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MARCORPS LAUNDRY/SHOWER MODULE - WASHING AND DRYING TEST PROGRA--ETC(U)

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INTRODUCTION

Traditional Marine Corps missions have historically required the highest possible level of readiness. These missions have often required rapid response to an already crisis situation. To maintain the high level of readiness necessary, manpower losses due to secondary (noncombat or housekeeping) activities must be kept to a minimum.

The Marine Corps Development and Education Command (MCDEC) has stated in Reference 1 that

> "As recently as World War I, disease caused almost half of the deaths of our fighting men. It wasn't until World War II that the tide changed and more men were killed by the enemy than by disease. Although disease caused only 5% of the U.S. deaths during World War II, it was the greatest cause for non-effectiveness. Various diseases and non-combat type casualties accounted for 85% of all sick-bay and hospital admissions."

As the potential for rapid response increases, the importance of constantly maintaining good health also increases. Unfortunately, the relatively sterile atmosphere of a training camp in the United States does not totally prepare one for living and working within a disease-infected combat environment.

At present Marine Corps personnel can neither clean clothes nor bathe while in a moving field environment. The only equipment available for such functions requires relatively stable surroundings with adequate water supply, time, and manpower to support equipment use. Unfortunately, most of the people who need the laundry/shower facilities have neither the water supply nor the time and manpower necessary for use of such facilities; consequently, bathing and cleaning clothes in the moving combat field is sporadic or in many cases nonexistent. Clean clothes, as well as clean bodies, are a necessity, however, regardless of the work surroundings. The combat field environment has the same requirements for hygienic conditions for both clothes and bodies as other surroundings with far greater consequences in the form of manpower/firepower loss if unhealthy conditions are allowed to exist.

The Naval Facilities Engineering Command (NAVFAC), with MCDEC, tasked the Civil Engineering Laboratory (CEL) to develop a self-contained, portable laundry and shower module for Marine Corps (MARCORPS) use that would be compatible with MARCORPS primary mission's resources and logistic support in combat field operations. A module containing laundry and shower facilities would be necessary in any environment, but was to be complementary to the combat tactical situation. The laundry and shower functions were to be made more compatible with each other, especially

with respect to time. The laundry and shower facilities operating in one module would facilitate transportation and operation in confined areas (e.g., shipboard use).

A major effort for the past 2 years has been evaluation of laundry systems that can wash and dry clothing within 5 minutes inside of a self-operating, modular package.

TYPES OF LAUNDRY SYSTEMS

Conventional laundry equipment employs the following major steps in washing and drying clothing:

1. Agitating clothes to maximize the contact of cleansing agents
2. Rinsing excess/residual detergent in clothes with large quantities of water
3. Spinning washed clothes to remove excess water
4. Drying clothes with hot air while tumbling

The laundry cycle (wash, rinse, dry) generally takes 70 to 90 minutes. The loading rates range from 8 to 25 pounds for domestic machines to 50 to 1,000 pounds for commercial units. Water consumption rates range from 1.5 to 5.0 gallons of water per pound of clothes (dry weight).

No known commercial laundry system can meet MARCORPS specific field operational requirement: to launder clothes within 5 minutes and, therefore, be compatible with users' shower time. A search was made for applicable state-of-the-art technology through review of United States and worldwide patents. The patents can be divided into three system types: (1) washing, (2) drying, and (3) those incorporating both washing and drying. These, summarized and reported in the following sections, are identified by designer or manufacturer.

Washing

Pace (Ref 2). A pair of screen-like, perforated belts transport cloth material past nozzle assemblies. The nozzles direct sprays of wash and rinse liquids at the material. The apparatus developed has a complicated configuration, yet the principle of using high speed, wash and rinse liquid spray nozzles is quite adaptable to the module.

Kennedy Engineers (Ref 3). This washing apparatus was patented for retaining bolts of cloth in an uncreased condition with a minimum of tension while the material is fed past nozzle assemblies. The cloth is drawn around part of the circumference of the rollers so opposite faces of the material are brought into contact with spray nozzles.

Bold and Scribens (Ref 4). Clothes, draped over hangers, are transported through a system of pressure water jets and squeegee rollers. Leaving the individual pieces of clothing on hangers alleviates much of the mechanical complexity of horizontal-loading conveyor systems.

Steiner Company (Ref 5). This continuous washing method, used for industrial processing of soiled fabric articles, imparts a cycloidal motion to dissociate soil. A tank holding a wash solution and a conveyor for transporting the soiled articles through the tank are used. Cycloidal motion is provided by moving the cloth in a back and forth motion over a series of rollers while the soiled articles are transported through the wash solution tank.

Beges (Ref 6). The articles suspended on hangers are sprayed with a washing liquid of soap or detergent. Movable nozzles spray the washing solution from above and below the hanging articles.

Guberman et al (Ref 7). Items in this dry-cleaning machine are moved along on a conveyor and are subjected to alternating ultrasonic vibration transducers and spray jets within a tank filled with a solvent medium. Air flow in this machine removes the water from the garments. This patented washing equipment was the closest in design to that tested by CEL.

Grantham (Ref 8). Clothes are sandwiched on a conveyor system and transported through different washing/drying stations. The cloth is subject to water sprays, mechanical scrubbing, and detergent application. Wringers and successive water spray jets along the conveyor path dewater and rinse the laundry. This conveyor system is much like the configuration used for the test program at CEL.

Wooliever (Ref 9). Clothes are confined between conveyor belts and progress through a series of tubs in which they are subjected to both vibration and water-jet action. Rinsing is provided by transporting the clothes through successive tubs of water. For dewatering, the clothes are alternately exposed to wringer rollers and to hot-air circulation.

Bahnsen (Ref 10). Clothes are confined between conveyor belts while they are transported through tanks of cleaning solution. Hundreds of rollers in the process subject the clothes to cycloidal motion. The clothes are transported through tanks of clean water for rinsing, and dried by hot-air circulation.

Drying

Steiner Company (Ref 11). This system is a high-speed continuous apparatus for drying wet porous cloth articles. The articles are transported through the heating chamber; they are subjected to repetitive processes of gas-fired infrared burners and air jets.

Staats (Ref 12). This microwave dryer includes a conventionally heated air source that rapidly exhausts moisture. In one embodiment of Staats' patent the drying chamber is a conventional home-type clothes dryer. Perhaps the most significant portion of the patent deals with a unique way to control the magnetron bulb's on/off operation, depending upon moisture content of the drying fabric. Assignee for this patent is the General Electric Company.

Hallier et al. (Ref 13). In this microwave drying oven for individual ceramic articles, moisture is condensed on the cooler walls of the oven away from the heated objects and is subsequently drained away.

Hurwitt (Ref 14). This continuous microwave drying oven for drying ceramic materials includes a continuous conveyor and auxiliary heated air source.

Williams et al. (Ref 15). This microwave drying oven includes multiple applications of microwave energy between sources of air circulation to aid the drying process.

Kenyon et al. (Ref 16). This apparatus sterilizes food in flexible pouches in a continuous process. Microwaves are used to heat the food to sterilizing temperature appreciably above the boiling point of water at atmospheric pressure. An overpressure - from about 25 to 40 psig - is applied to the interior of the microwave processing tunnel to prevent bursting of the flexible package material during the heating process.

Washing and Drying

Bahnsen (Ref 17). With this laundry apparatus, fabric articles are transported on a screen-like, perforated belt along a winding path through an alkaline solution and a detergent solution. In both solution tanks, the fabric is subjected to cycloidal motion at a rate of 400 cpm. The articles are then rinsed by forcing a mixture of water and gas repeatedly through the articles in a countercurrent manner. The articles, transported along on a horizontal conveyor, are dried by subjecting them successively to radiant heat and blasts of warm air.

Pfeil (Ref 18). With this two-step cleaning process for textile materials, a high concentration of surfactant is applied at relatively low energy levels, followed by a low concentration of surfactant applied at high energy levels. The high and low concentration of surfactant may differ by a factor of 50, while the high and low energy levels may differ by a factor of 100. The energy is transmitted via high frequency vibrations, such as ultrasonic waves. Pressurized hot water is used for rinsing, and the fabric is passed onto hot surfaced rollers for drying.

Kirkby (Ref 19). This machine launders garments on hangers. A vertical conveyor lifts the garment on a hanger and transfers the hanger to a stationary conveyor along which it travels through a series of spraying chambers and dripping chambers. The final process includes a chamber for drying the clothes, which remain on the hangers.

State-of-the-Art Summary

Review of the patents described above indicated that state-of-the-art technology can be utilized to assist in the creation of a laundry system to meet MARCORPS field operation requirements. Major shortcomings in these patented laundry machines are exorbitant size and weight and complicated mechanical equipment. Also, no wastewater treatment and recycling options are provided in these machines.

From the state-of-the-art and patent investigations, a pattern was observed in the processes for washing and drying clothing. For washing, these processes were observed in the literature in one form or another: ultrasonic vibration, low frequency vibration, high velocity water jets, low velocity water jets, and mechanical rollers.

Of the washing processes observed, mechanical rollers were considered less feasible than the other processes because of the complicated mechanical systems involved. These systems do not lend themselves as readily as the other methods to field-oriented equipment.

For drying, these processes were observed repeatedly: microwave radiation and infrared radiation.

Microwave radiation appeared to be, by far, the obvious choice. To evaporate the quantity of water necessary on an hourly basis, an infrared energy source would have to be a large gas-fired system, making it incompatible, therefore, with MARCORPS requirements for size and use of electricity as the exclusive power source for the module.

The evaluation testing program with the chosen washing and drying processes was conducted during FY77; mechanical rollers and infrared radiation were not included.

LAUNDRY/SHOWER MODULE DESCRIPTION

At the start of work on the laundry/shower module concept, it was recognized that batch-style conventional washing and drying machines could not be modified to mechanically provide the 2.5-minute wash cycle and the 2.5-minute dry cycle for each set of clothing. An additional disadvantage was the necessity of providing an operator to oversee the loading/unloading of the washer and dryer in the least possible time. Time wasted between the washing and drying cycles alone did not permit the 2.5-minute time periods necessary. Therefore, a conveyor was devised to automatically transport the clothes through the washer and dryer processes.

The conveyor, shown in relation to the entire module in Figure 1, is the key to reducing the time to launder clothes, and consequently to the successful development of the laundry system. Clothes are placed on the moving conveyor located in the undressing room. As the clothes are transported through the wash, rinse, and dry cycles, a person will be taking a shower all in the same 8 x 8 x 20-foot module. After 5 minutes of treatment, the clothes are deposited in the dressing room located at the far end of the module. Personal items and boots are either carried in a waterproof bag or transported via a separate conveyor depending upon future design constraints. The laundering process time required per set of utilities (jacket and trousers), underwear, and socks can be as short as 5 minutes. The time required for processing a total amount of clothing is calculated as follows:

(no. of people)(set of clothing entrance/exit rate)

+ (no. of minutes processing time through system)

= total processing time

For 250 people the processing time is:

$$(250)(0.5 \text{ min}) + (5 \text{ min}) = 130 \text{ min} = 2 \text{ hr}, 10 \text{ min}$$

This is assuming a conveyor speed of 10 fpm. Each set of utilities and underwear represent 5 pounds of clothing; therefore, the rate of laundry processing is about 10 pounds of clothing/min or a total of 1,250 pounds of clothing.

It should be noted that the 0.5-minute entrance/exit rate indicated is the time interval necessary for one set of clothing to enter the laundry equipment. Since troops should be lined up waiting to enter the laundry/shower module, the pattern of clothing on the converyor should be a continuous one, without appreciable intervals between the various sets of clothing.

The 2-hour, 10-minute processing time for 250 people corresponds to a 2-minute showering time per person (four people showering simultaneously). During recent conversations with MARCORPS representatives, a 4-minute showering time (and consequently a 4-hour, 20-minute processing time) was considered acceptable, especially if power expenditures become significant for clothes drying. Finalized power expenditures will be sent to MARCORPS representatives when they become available for final determination of the laundry/shower processing time period.

The water-use rate to bathe 250 people and launder their clothing in a 2-hour period is:

4 shower heads @ 2.5 gpm	=	10 gpm
laundry	=	10 gpm
TOTAL	=	20 gpm = 1,200 gph

The total water requirement for a 2-hour period is 2,600 gallons. The maximum water usage for 250 people to allow helicopter transportation of the water supply is 1,000 gallons (8,340 lb). Therefore, the water reuse system must be capable of recycling the laundry/shower wastewaters two to three times, assuming a water recovery rate of 80%. The water loss from the laundry/shower system via clothes and bodies is approximately 0.8 gallons for each person, or 200 gallons total for 250 people. Such loss will not significantly affect the recycle system.

The power requirement for the system is a most important parameter to be considered. The power is directly related to the amount of time necessary to satisfactorily wash and dry the clothing. Decreasing the laundry time increases the amount of power necessary to accomplish the

laundry process. Because of weight constraints the maximum power generator possible for use in the field is 200 kW (10,500 lb). This generator will allow transport via helicopter and if not already in place will represent the third load* for the laundry/shower system. Since exploratory development work is not yet completed, power requirements at present are best estimates. Work in FY78 will strive to reduce the water and power expenditures wherever possible. A full description of the power requirements and the power-versus-process-time relationship is explained in detail in the CONCLUSION section of this report.

A complete set of evaluation criteria is listed in the Appendix. These criteria will be used to aid in the eventual design of the prototype module. They were designed to initiate input from MARCORPS personnel.

WASHING TEST PROGRAM

The major emphasis of the laundry testing program has been to speed up the basic processes of removing dirt and other contaminants from clothes, to rinse the clothes to remove all residual detergent and dirt, and to dry the clothing once cleaned.

The washing process time was shortened by increasing the turbulence of the water/detergent environment surrounding the clothes. Greater turbulence means greater contact between the detergent in the water and dirt adhering to the cloth fibers. Creating increased turbulence by altering washing machine action has been shown to correlate well with increased cleaning efficiency (Ref 20). This observation has been corroborated in testing programs designed to evaluate the relative cleaning efficiency of the four major types of today's washing machines. In order of decreasing cleaning effectiveness these are: impeller, dunker, agitator, and drum.

The drum type of washing machine or "front loader" is used extensively in the commercial laundry business. Clothing is stirred as the drum, partially filled with water and detergent, rotates on a horizontal axis. Agitation is provided by the clothes being dropped into the water after vanes, attached to the drum side, have lifted the clothing from the water. The agitator and dunker washing machines or "top loaders" are used most extensively in American homes. The agitator comprises about 90% of American washing machine production (Ref 21). Both the agitator and dunker machines have a center column on a vertical axis which provides the agitation for the washing cycle. The agitator's vertical column and attached fins oscillate 180 degrees back and forth, moving the water and clothing as it does so. The dunker's vertical column and attached cones oscillate with a rapid vertical reciprocating motion causing an up-and-down motion.

The impeller type of washing machine is used extensively in Europe and Japan and is also a top loader. Located at the bottom or side of the bowl, an impeller, rotating at a relatively high revolution, causes the water and clothing to stir. This impeller doesn't actually touch

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*First load = module; second load = water.

the clothing, it merely rotates the water and in so doing creates a great deal of turbulence. Its superiority in creating turbulence explains its cleaning superiority over the other washing machine types.

This correlation between turbulence and washing effectiveness is due both to the increase in contact between detergent and the cloth, and the physical dislodging of the dirt from the cloth's fibers. This correlation served as the basis for the wash testing program conducted during FY77: to shorten the time required to clean clothes by increasing the turbulence within the wash tank.

Alternatives

The turbulence-promoting processes chosen for feasibility testing were: (1) low frequency vibration, (2) ultrasonic vibration, (3) high velocity water jets, and (4) low velocity water jets.

The low frequency vibration and high velocity water-jet testing was conducted using proprietary equipment developed for the cloth manufacturing industry. A cross-section schematic of the vibration device is shown in Figure 2. As can be seen, fabric travels over a perforated casing. The rotation of the uneven drum below this casing acts to push water out of the perforation when the "hill" of the drum travels below the hole and acts to suck water into the perforation when the "valley" of the drum travels below the hole. This inward/outward movement of water creates a tremendous agitation which has proven successful in cleaning continuous bolts of cloth (Ref 22). Modifications to this system to accept individual pieces of clothing instead of the bolts of cloth consisted of "sandwiching" the clothes between two nylon mesh conveyors and running the conveyors over the vibration-equipment casing.

The high velocity water-jet configuration consisted of two banks, each of which contained 60 nozzles, where a 20-gpm flow was attained through each nozzle (2,400 gpm total). This tremendous force accomplished two functions at the same time: final cleaning and rinsing. Rinsing is no more than diluting the detergent so it can no longer hold the dirt in suspension, and the high volume of water from these water jets demonstrated an almost instantaneous rinsing effect. These spray nozzles have been used successfully in the cloth manufacturing industry for cleaning of cloth before and after adding dyeing agents (Ref 23).

CEL evaluated the feasibility of ultrasonic vibration and low velocity water jets for cleaning individual pieces of clothing. The test bed used is shown in Figure 3; a schematic of the conveyor movement within the bath is shown in Figure 4.

The ultrasonic equipment used, purchased from Branson Ultrasonics Corporation, consisted of a 2,000-watt, 25,000-kHz generator and four immersible transducers each 6 inches long x 18 inches wide x 3-1/4 inches high. Each of the four transducers contained 12 vibrating elements with a total power output of 4 W/sq in. (≅0.6 W/sq cm). This power level was recommended specifically for the water/detergent medium used to maintain a high level of cavitation throughout the 6-inch space between the transducers. Previous testing had shown that cavitation could be maintained on the surface of utility clothing and through one

or two layers. Since the number of layers of utility clothing is greater than two in many areas (e.g., pockets), two 18-inch transducers, end-to-end, were placed on the top and bottom of the clothing to insure sufficient vibratory levels for all clothing parts.

The low velocity water-jet configuration consisted of 12 banks, each containing 9 nozzles. A 2-gpm flow was attained through each nozzle (216 gpm total). The nozzle face was 3 inches from the conveyor for all the nozzle assemblies. The first set of four nozzle banks were directed at an upward angle (approximately 30 degrees) from either side of the conveyor as the clothes entered the bath. A main function of these nozzles was to degasify the clothes as soon as possible upon entering the bath area. The gases in the cloth must be stripped in order for intimate contact to be initiated between the detergent in the water and the dirt on the clothes. Wetting agents will accomplish this in time; however, a forceful spray of water and wetting agents (contained within the detergent composition) improves removal of these gases. The second set of four nozzle banks struck the clothes perpendicularly from either side of the conveyor as the clothes traveled horizontally across the bottom of the bath. These nozzles provided a forceful, turbulent area for complete detergent/dirt contact. Continuous rewetting, dirt removal, emulsification of dirt and oils, and contaminant suspension were accomplished here. The third set of four nozzle banks were directed in a downward angle of approximately 30 degrees from either side of the conveyor as the clothes exited the bath. A main function of these nozzles was to physically dislodge dirt particles which may have been loosened but were still adhering to the cloth. This is not a rinsing action because the water flowing through the nozzles (as with the other nozzles) contains the normal detergent concentration used within the bath; it is rather a final cleansing surge. The clothes which exit the bath go through a wringer device, two banks of nozzles each containing nine outlets (2 gpm/nozzle), and through a final wringer assembly.

During the test program, impeller-type, agitator-type, and industrial sized drum-type washing machines were tested so that the experimental washing systems could be compared.

After observing the relative cleanliness of processed clothes from the three machines, the cleaning quality of the industrial machine with a 75-pound load became the goal of the testing program. The cleaning efficiency of the smaller washers with 16-pound loads (especially, the impeller type) was superior to the industrial unit. However, this is due in part to the small loading capacity and the consequent high ratio of water and turbulence to pounds of clothing (2.5 gallons of water per pound of clothing with the home washer versus 1.4 gallons of water per pound of clothing for the industrial washer).

Measurements

In order to measure quantitatively the cleaning effectiveness of the various tests, pieces of test fabric were sewn into camouflaged utility jackets at four locations as shown in Figure 5. A fifth piece was clipped to a trailing edge of the garment to see if the cleaning

process was affected by the mass of clothing to which the other pieces were attached. The test fabric, as shown in Figure 6, was purchased from Testfabric, Inc. and contains a soiled half as well as a clean white half. The procedure for measuring the amount of soil removed from the cloth was in accordance with conventional practice and involved measuring the reflectance from a known light source of the soiled cloth before and after washing (Ref 24 through 26). For this purpose a Photovolt Reflection Meter was used with a green tristimulus filter. The reflection meter is designed for measuring the diffuse reflection of surfaces such as fabric, paper, etc. Its light source is placed on the material to be measured and the amount of light reflected at 45 degrees from the material's surface is indicated on an attached galvanometer. The premise of this measurement is that soil on the fabric surface causes the light to be reflected at an angle other than 45 degrees or is absorbed. The amount of light which is reflected at the 45-degree angle is constantly measured and increases as soil is removed from the cloth section. For all tests conducted with the low frequency vibration and high velocity water jets, a recording spectrophotometer was also used to measure reflectance from the test fabric throughout the visible wavelength spectrum between 400 and 760 mμ. Throughout these tests the correlation between the spectrophotometer and reflectometer was excellent. Therefore, the reflectometer alone was used for the testing conducted at CEL. The reflectance reading was converted into a measure of washing/cleaning effectiveness by the following formula (Ref 25).

$$\text{Percentage of cleaning effectiveness} = \frac{S_A - S_B}{W_A - S_B} \times 100$$

where S_A = reflectance of washed, soiled sample

S_B = reflectance of unwashed, soiled sample

W_A = reflectance of washed, unsoiled sample

The cleaning effectiveness formula is actually a numerical representation of how much soil was removed by the laundry process without redepositing into the adjacent unsoiled portion. During the CEL tests, white laboratory coats were washed under identical condition of tests as those using the test fabric. Reflectance readings were taken as before to insure that the test fabric desoiling effects were not unique to this fabric, but rather demonstrative of the process used regardless of test cloth.

Cleaning Tests

The cleaning tests performed included:

1. Ultrasonic vibration
2. Low velocity water jets

3. Ultrasonics and low velocity water jets
4. Low frequency vibration and high velocity water jets
5. Drum washing machine (conventional industrial use)
6. Agitator washing machine (conventional home use)
7. Impeller washing machine (conventional home use)

The low frequency vibration and high velocity water-jet testing, and the impeller laundry machine testing were conducted under contract to Rudnick Associates, Inc. representing Diawa Machinery Works, Ltd. All other testing was conducted by CEL.

Table 1 shows the conditions subjected to the various washing machines. No attempt was made to alter the normal washing cycles of the conventional washing machines.

Results

Figures 7 through 14 show the cleaning results of the test program. Figure 7 shows an average of the test results attained with the conventional washing machines used during the program. As previously mentioned the commercial washing machine (75-pound load capacity) was considered demonstrative of large scale washing operations and was designated as the cleaning objective of the test program. Therefore, a 41% cleaning-effectiveness value is considered the cleaning objective for the washing portion of the test program. As can be seen this level of cleaning was surpassed by the agitator washing machine (except position 4) and greatly surpassed by the impeller washing machine. For these tests, the utility jacket with test fabrics attached were placed within the washing machines in addition to other clothes necessary to make up a typical cleaning load.

Figures 8-11 show an average of the test results achieved with the combination of low frequency vibration and high velocity water jets. The cleaning objective was surpassed in every test (except position 4) within a 5-minute time period using less detergent than conventional washers and cold water. For these tests, the utility jackets with test fabrics attached were held in place around the low frequency vibration device for 4.5 minutes and subjected to the high velocity water jets for 0.5 minutes.

Figures 12-14 show an average of the test results achieved using ultrasonic vibration, low velocity water jets, and the combination of ultrasonic vibration and low velocity water jets. The cleaning objective was surpassed on an average within a 4.5-minute time period using ultrasonics alone, within a 4.5-minute time period using low velocity water jets alone (except position 4), and within a 6-minute time period using a combination of ultrasonics and low velocity water jets (using less power, however). These tests were performed using less detergent and a lower water temperature than is used with the conventional washing machines. For these tests, the utility jackets with test fabrics attached

were carried between the transducers or nozzles of the cleaning apparatus a number of times with each pass corresponding to a particular retention time.

The significance of the various retention times is power usage. This is discussed in detail in the conclusion portion of this report.

DRYING TEST PROGRAM

Conventional clothes drying processes require the transfer of heat from large quantities of air to the fabrics (mainly by convection and conduction) in order to evaporate the fabric's moisture content. A high percentage of heat is therefore wasted due to the continuous heating of large volumes of cool air and the continuous exhaustion of the heated air to the atmosphere. Besides requiring large quantities of heat, this process requires substantial time to heat the air, to allow the air to heat the fabric and water, and finally to evaporate the water. Conventional clothes-drying times range from 20 to 70 minutes, depending upon fabric material, loading conditions, and ambient air temperature and humidity.

To offset conventional drying characteristics, microwave radiation has been chosen for testing purposes. The uniqueness of microwave energy for drying lies in its ability to contact the water molecules directly without heating the air appreciably around the fabric. The microwave contact causes the molecules to move back and forth at extremely high rates of speed to produce heat through friction. The currently available microwave bulb generators cause this movement at 2.45×10^9 cpm (2,450 MHz) or 9.15×10^8 cpm (915 MHz) for commercial heating and drying applications. The 2,450 MHz frequency generates a shorter wavelength (4.8 inches) than the 915 MHz frequency (13.5 inches). These shorter wavelengths produce more uniform heating and, consequently, better results for small objects, but they are much more difficult to attenuate than the large wavelengths.

To cause microwave attenuation for equipment being used continuously because of the required open doors, it is necessary to provide attenuating tortuous paths called radio frequency chokes or water jackets at the chamber openings. The amount of attenuation necessary is dictated physically by the power densities used within the chamber and legally by the safe limits set forth by applicable legal authorities. In the case of the laundry/shower module, the legal authority is the Naval Bureau of Medicine and Surgery (BUMED) which has established the following power densities and corresponding exposure times as follows:

1. Continuous exposure average power density is not to exceed 10 mW/sq cm.

2. Intermittent exposure incident energy level is not to exceed 300 mJ/sq cm/30-sec interval. The Naval Environmental Health Center (Ref 27) has surveyed three Navy activities and reported its findings on microwave levels throughout the test sites. These same procedures will be used to insure all microwave dryer designs comply with current safe limit standards.

Microwave leakage throughout the test program was measured by a leakage monitor manufactured by the Narda Microwave Corporation, Plainview, N.Y.

In addition to the drying capability of microwaves, this energy source also possesses disinfection potential. This has been shown in research projects as well as with a commercial device developed by Oceanography International Corporation (Ref 28) to kill weeds and other soil pests. The food industry in the United States is also testing food sterilization while the foods are containerized in materials which allow the microwaves to pass through. The capability of disinfecting clothing will greatly enhance the use of microwaves for clothes drying because of the inherent hygienic benefits derived from processing clothes free from pathogenic microorganisms.

Pepperman et al. (Ref 29) showed microwave heating does not adversely affect coatings or finishing agents placed on fabrics. Flame-retardant chemicals were used during these tests, but other coatings such as water-repelling chemicals may be similarly less damaged or removed by microwave drying when compared to conventional drying methods.

Experimental Microwave Dryer Design

Each major piece of clothing (e.g., jacket or trousers) requires evaporating 1.5 pounds of water after mechanical wringing. This water content, to be dried within 2.5 continuous minutes, is about 7 pounds of water evaporated per minute. The total Btu value required is estimated by the following equation:

$$Q = W\,(Cp)\,\Delta T$$

where Q = heat energy required, Btu

W = weight of water to be evaporated, lb

Cp = specific heat, Btu/lb/°F

ΔT = temperature gradient, °F

$$Q = (7)(0.4)(220 - 70) \text{ clothes sensible heat}$$

$$+ (7)(1.0)(220 - 70) \text{ water sensible heat}$$

$$+ (7)(970) \text{ water latent heat}$$

$$= 8{,}260 \text{ Btu}$$

The laboratory microwave dryer used for testing is an 8-kW system that may be used either as a batch or continuous system. Overall dimensions are 65 inches high x 43 inches wide x 96 inches long, and weight is about 350 pounds. Five 140-cfm fans are used for bulb cooling and vapor exhaust.

Drying Tests

Experiments conducted at CEL were in batch-type operation. Clothes to be dried were weighed before and after soaking in water and mechanical wringing. The clothes were again weighed after drying. Table 2 shows the water absorption capacity of two different types of military utilities. Although the camouflaged utilities absorbed more water than the green utilities, water removal via wringing was greater for the camouflaged fabrics (Table 2). The mechanical wringer removed between 21% and 43% of the moisture absorbed by the utility fabric. Since the microwave energy used to dry the clothes is directly proportional to the water content of the clothing, a more consistently high wringing capability must be sought.

Results

Table 3 shows the conditions for 15 of the experimental tests conducted using the experimental microwave clothes dryer. The experimental dryer demonstrated relatively consistent overall drying efficiencies (i.e., 26%).

The only problem encountered was a charring of the fabric on two occasions because the cloth became overdried (drier than the clothes' original dry weight). This condition may be avoided by monitoring the moisture content of the dryer's exhaust gases in order to regulate the magnetron bulb's operation. During run 7, metal coins and paper clips were placed in the pocket where the charring of the fabric occurred. Further work will identify all characteristics which precede fabric damage in order to design this effect out of the dryer system.

As shown in Table 3, the actual drying times varied greatly, depending upon moisture content of the clothes and power input. Where the moisture content of the clothes was constant (e.g., runs 1 through 4) the relationship between power and drying time was inversely proportional and linear. Clearly, to decrease the clothes drying time, one must increase the power requirement. This is reflected in Figure 15 and is discussed in the DISCUSSION section of this report.

WASTEWATER RECYCLING

Treatment Process

Wastewater recycling is essential in order for the proposed laundry/shower module to operate in a remote field environment. Water will be recycled daily to accommodate the 250-man-use cycle. Assuming 2,600 gallons of water will be necessary daily (5-gal/cycle shower 5-gal/cycle laundry) for use within the module, two to three wastewater-treatment use cycles will be performed on the initial charge of 1,000 gallons. The number of wastewater treatment cycles may, however, increase if the initial charge of water is decreased. This would in turn reduce the

transporting weight requirement. For example, an initial charge of 500 gallons requires six treatment/use cycles instead of the three mentioned earlier.

The four water treatment processes that offer the effectiveness necessary to recycle laundry/shower water within the size and operating constraints of the field module are shown in Figure 16. Each system will be evaluated on actual wastewaters to ascertain their relative cost effectiveness while operating with the laundry/shower module. Important operational parameters to be considered within the test program include operation and maintenance requirements, manpower expenditures, chemical resupply, equipment reliability, and power and size requirements.

Reverse Osmosis. The first candidate system is reverse osmosis (RO). Of the four systems shown, RO will give the best quality product water (Ref 30, 31). However, the capability of removing a large variety of wastewater contaminants makes RO vulnerable to membrane fouling from an almost equal variety of substances. To minimize the fouling effects of the wastewater contaminants, a low packing density configuration will be employed to facilitate cleaning effectiveness. A tubular configuration will be used for initial test purposes. Pizzino (Ref 32) showed that a noncellulosic RO membrane exhibited greater than 90% rejection of total solids and chemical oxygen demand and 98% rejection of nonionic detergents while operating on actual laundry wastewater. During the 900 hours of test program operation, the membrane exhibited a 2 to 6 gal/sq ft/day (GFD) permeate flux. This low permeate flux may exclude RO due to size limitations within the laundry/shower module.

Ultrafiltration. The second flow scheme (shown in Figure 16) uses ultrafiltration as the primary treatment process. Ultrafiltration (UF) has been used successfully in research testing programs for concentrating shipboard sewage in a variety of configurations (Ref 33, 34). UF has been successful in treating shower wastewater (Ref 35) and laundry wastewater (Ref 3) individually. While used with laundry wastewater, a hollow fiber UF module was capable of 95% recovery while averaging about 20 GFD permeate flux. During the tests, a 72% chemical oxygen demand (COD) rejection was attained. Cleaning of the membrane by back pressurization was moderately successful, indicating the possibility of physically cleaning this configuration without the aid of chemicals.

During recent testing, Lent (Ref 36) showed that a relatively low packing density of the hollow fiber configuration successfully operated on shower wastewater without the need for cleaning chemicals also by using a backflushing technique.

This alternative has perhaps the greatest probability of success due to its compact size and its effectiveness to remove contaminants above a specific molecular weight cutoff (e.g., 50,000).

Air Flotation. The third alternative is perhaps the best known process for treating laundry wastewaters. Numerous reports have identified the coagulation/flocculation properties of laundry water with the addition of various chemicals in conjunction with the air-flotation process (Ref 37 through 41). At least two air-flotation processes,

which use proprietary chemical additives, are being used presently to recycle the wastewater in commercial laundries (Ref 43, 44). The logistic burden associated with chemical resupply for military field application may preclude this method for wastewater reuse. However, depending upon water and sewer costs, consistent and cost-effective wastewater reuse can be, and has been, demonstrated at one commercial laundry over the past few years (Ref 44).

Filtration and Carbon Adsorption. The fourth alternative incorporates a relatively low sensitivity filter (≈ 1 μm) with carbon adsorption. The carbon in this case may either be powdered or in granular form. Fouling or blinding of the filter material and premature, low molecular weight, organic breakthrough of the carbon will be prime considerations in evaluation of this process. Quantity of carbon used will also be an important parameter for investigation because an extensive logistic requirement for this or any of the alternative systems is unacceptable for a field-oriented water treatment system.

Other Factors. Although none of the alternatives specifically requires a chemical coagulation and flocculation stage, various chemicals will be used in small amounts to enhance the efficiency of the various processes. Also, pH reduction via chemical addition will be required to produce acceptable shower water in all the alternative water treatment systems.

Tests During FY-78

Preliminary testing of various water treatment processes has provided the data shown in Table 5. No chemicals were used during the first three tests; however, for the last test a combination of proprietary coagulant, alum, and polyelectrolyte was used. The filter used in test no. 1 was an in-line fabric type with a nominal pore size of 30 μm. This filter was used as a prefilter to a dispersed air-flotation stage of test no. 2 as well as the ultrafiltration stage of tests no. 3 and 4. The ultrafilter media had a nominal 50,000 molecular weight cutoff. These tests were run primarily to get an idea of typical rejections for various stages within the proposed wastewater recycling alternatives. As can be seen from the data, the ultrafiltration unit effluent represents substantial reductions in the major contaminant indicators; i.e., COD, total alkalinity, suspended solids, and turbidity. Further reductions are required in terms of organic removal as indicated by the COD residual remaining in the effluent, but this is not expected to pose a significant problem when in-depth experimental model testing commences.

Characteristics of Wastewaters From Shower and Laundry

Wastewater generated from showers and laundries includes the following "additives" to the original water used:

1. Physical: heat, turbidity, foam, odor, color, and solids (grit, lint, etc.)
2. Chemical: sodium chloride, lactic acid, urea, soap (such as sodium dodecylbenzene sulfonate), detergent (such as linear alkylate sulfonate), and other dissolved solids which include free fatty acids, glucose, amino acids, paraffins, uric acid, and other organic materials.
3. Biological: coliform and other bacteria, viruses, other microorganisms.

All of the above additives, except soap and detergent, result from the human body or from clothes' contaminants. Depending upon how effective the wastewater treatment processes are, some of the additives will accumulate when the wastewater is reclaimed and reused. A significant factor for successful development of a reuse treatment process for this particular laundry/shower application is that freshwater can replace the old after every 250 uses. Soluble contaminants which are most difficult and consequently expensive to remove from a water source can be allowed to accumulate when their concentration remains within acceptable levels by keeping the number of reuse cycles to a minimum and providing an initial high water dilution.

At the present time there are no Navy/Marine Corps accepted standards for reusing shower and laundry wastewater. The Safe Drinking Water Act of 1974 gave the Environmental Protection Agency the power to set maximum limits on the level of contaminants permitted in drinking water. These limits may become the basis for water reuse for potable usage in the future but are too restrictive for body contact purposes such as shower and laundry water. Table 4 shows the tentative wash water quality standards established by the National Academy of Sciences, National Research Council in the NASA program for prolonged space travel (Ref 46). The linear alkyl sulfonate (LAS) recommendation comes from both the Coast Guard and Army work aimed at reusing shower water for laundry water purposes. Some of these water quality components lend themselves to in-line, real time monitoring equipment which will be necessary for routine reuse of body contact water on a daily basis.

Until better laundry/shower reuse standards are formulated the standards shown in Table 4 will be the objective of the water recycling work accomplished within this laundry/shower development program.

DISCUSSION

Washing Tests

The tests conducted with conventional washing machines confirmed the relative cleaning ability of impeller, agitator, and drum washing units. Certainly the size of the clothing loads is a contributing factor because the turbulence exerted and water used per pound of clothing

decreases as the loading capacity of the machine increases. Under relatively ideal conditions (0.5% detergent concentrate, 60°C water temperature) the commercial sized washing machine removed soil from the test fabric at a rate of 41%/50-min washing cycle. This cleaning capability is considered the objective for the washing portion of the laundry work and can be seen from Figures 8 through 14; this objective was realized with all the processes tested within varying time periods. Figures 8 through 11 show the drastic change in cleaning experienced on the outside of the utility jacket compared to inside the pocket (position 4). For water temperatures 30°C and above and detergent concentration 0.25% and above, similar cleaning results occurred for positions 1, 2, and 3. Fabric cleaning inside the pocket, however, increased significantly with increasing water temperature. Presumably the interaction between the detergent in the water and dirt within the pocket was affected more by thermal kinetics, than by the mechanical action or detergent concentration of the cleaning solution.

The overall cleaning efficiency of the low frequency vibration and high velocity water jets within the 5-minute time period was better than anticipated. The possibility of cleaning clothes with cold water, less detergent than conventional use, and in much less time was clearly demonstrated.

Figures 12 through 14 show a more subtle change in cleaning effectiveness from position to position. The water temperature and detergent concentration levels used were considered optimal from previous laboratory bench scale beaker testing.

The lack of change and the similarity of the results for Figures 13 and 14 indicate the lack of effectiveness of the ultrasonic vibration while the water jets were activated. The interaction of the two processes causing this condition may have been the underwater currents caused by the water jets moving away from the cloth in the proximity of the transducers. This may have kept the cavitation bubbles from exerting their turbulent effect on the cloth as evidenced in Figure 12.

The parameter of true comparison for the various cleaning systems tested is the power necessary to achieve the required cleaning with the conveyor speeds required for Marine Corps application.

Figure 17 is a representation of the time necessary to launder 250 sets of clothing under varying conveyor speeds. As indicated previously by the formula in the LAUNDRY/SHOWER MODULE DESCRIPTION section of this report, the controlling factor for determining the quantity of clothes processed within a specific time period is the conveyor speed – not the retention time of the clothes through the laundry system.

As shown on Figure 17, the total time necessary to launder 250 sets of clothing doubles (from 2.2 hours to 4.4 hours) when the conveyor speed is decreased from 10 to 5 fpm, respectively. This is assuming a constant total laundering time of 5 minutes for both cases.

The significance of the conveyor speed is not only evidenced with total processing time required, but also affects the power requirements for the laundry process as shown in Figure 18. Although the cleaning results of the ultrasonic vibration and low velocity water jets were acceptable under the test conditions, these processes are extremely high

in power consumption under working conditions where a moving conveyor must be kept in constant contact with the high turbulence for periods of up to 5 minutes. The linear increase of power consumption is due to the linear increase of cleaning equipment as the conveyor speed increases. For example, the ultrasonic vibration process requires 25 feet of transducer length when the conveyor speed is 10 fpm (2.5-minute retention time) but only 12.5 feet of transducer length when the conveyor speed is 5 fpm (2.5-minute retention time). These transducer lengths convert to power requirements of 200 and 100 kW as the conveyor speeds decrease from 10 to 5 fpm, respectively.

Figure 18 clearly shows that the combination of low frequency vibration and high velocity water jets is the most power conserving of the cleaning processes tested when a conveyor speed greater than 1 fpm is required. Thus, this process is the recommended cleaning method for the laundry/shower module. The discontinuity observed between conveyor speeds of 5 and 6 fpm is due to the requirement to double the rinsing spray jets for conveyor speeds greater than 5 fpm. The combination of low frequency vibration and high velocity water jets requires 48 kW for washing clothes while operating under the following conditions:

Clothes retention time	2.5 min
Rate of clothes entering system	0.5 min/set
Conveyor speed	10 fpm
Total processing time for 250 sets of clothing	2.2 hr

Drying Tests

The tests conducted with the microwave dryer demonstrated the capability of using microwave energy to dry the required amount of clothing within the required time period. Hot air addition is required, however, to exhaust the required quantity of moisture continuously.

Although burning of some clothes did occur during the test program, microwaves have the potential of drying clothes faster than any other drying method now available and yet affect coatings on the fabrics less than conventional drying systems.

Figure 15 shows the power requirements of a continuously operating microwave clothes dryer capable of processing the required quantity of utility clothing necessary for MARCORPS operation. The percentage of water removed before drying (for example, by using wringers) was estimated to be 25% of the total water absorbed by the clothing. This estimate is conservative, and future system optimization will strive to increase water removal within the clothing before the drying process. The power shown is consumed in operating the microwave bulbs and in supplying hot air to aid in moisture evacuation from the dryer's chamber.

As shown in Figure 15, the total power requirement for drying 250 sets of clothes in 2.5 and 4.5 hours is 149 kW and 75 kW, respectively. These power requirements correspond to conveyor speeds of 10 fpm for 2.5 hours of operation and 5 fpm for 4.5 hours of operation. As previously

mentioned, the conveyor speed is the significant parameter necessary to determine the number of clothing sets processed in a specific time period; in this case, 2.5 and 4.5 hours. The power difference of 75 kW in the dryer operation alone is substantial and must be considered when the final operational scenario is formulated for the laundry/shower module.

Table 6 shows the total power requirements for the laundry/shower module with two previously mentioned total laundry processing times. As can be seen, the dryer's power expenditure is most radically affected by changing the conveyor speeds (and consequently the processing times). This is due to the classical thermodynamic laws governing the evaporation of water. Future work will concentrate on reducing the power expenditure of the drying unit by reducing the water content of the clothing before it is subjected to microwave energy.

The evaluation criteria for the laundry/shower module are presented in the Appendix. This list may change in the future due to input from MARCORPS personnel. One area of possible change is in the requirement that only electricity is acceptable as an energy source. A hot water heater, fired by conventional fuel, for the shower water could save over 30 kW from the power requirements shown in Table 6.

CONCLUSIONS

1. All the washing methods tested possessed the potential to satisfactorily wash clothing in 5 minutes or less.

2. The cleaning effectiveness was greatest for the low frequency vibration and high velocity water jets process.

3. Cold water temperature (20°C) and detergent concentration levels (0.25%) below normal can clean clothing compatible with conventional temperatures and detergent concentration with the tested high turbulence washing methods.

4. The power requirements for the laundry operation to process 250 sets of clothing may dictate that a 4.5-hour processing time is more realistic than a 2.5-hour period. In line with this, a 4-minute shower (4.5-hour total) may be more realistic than the originally planned 2-minute shower (2.5 hours total).

5. Microwave energy has the potential to dry the required quantity of water while utilizing only electric power.

6. Ultrafiltration has the greatest potential as the primary wastewater recycling method from the processes tested thus far.

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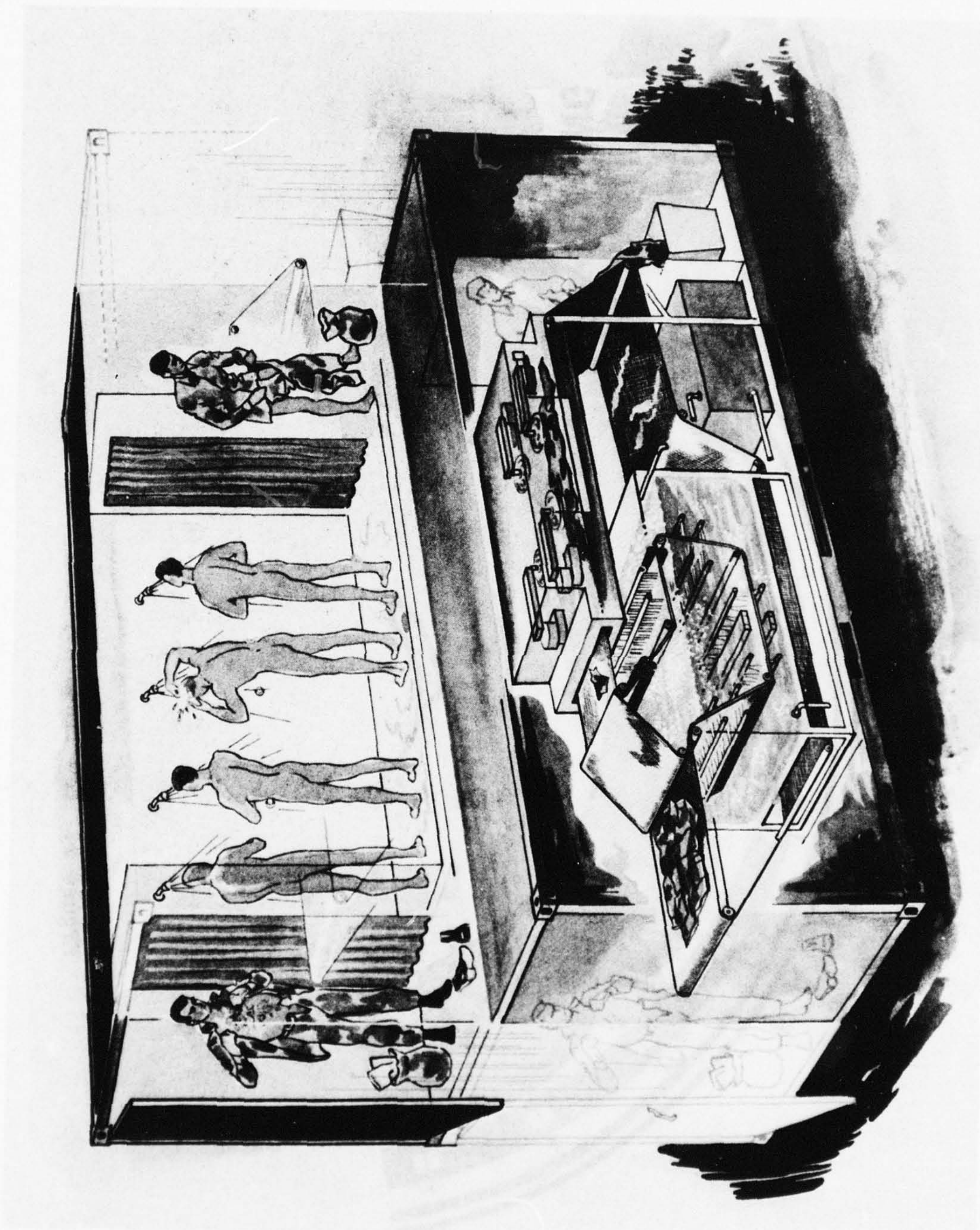

Figure 1. Laundry/shower module.

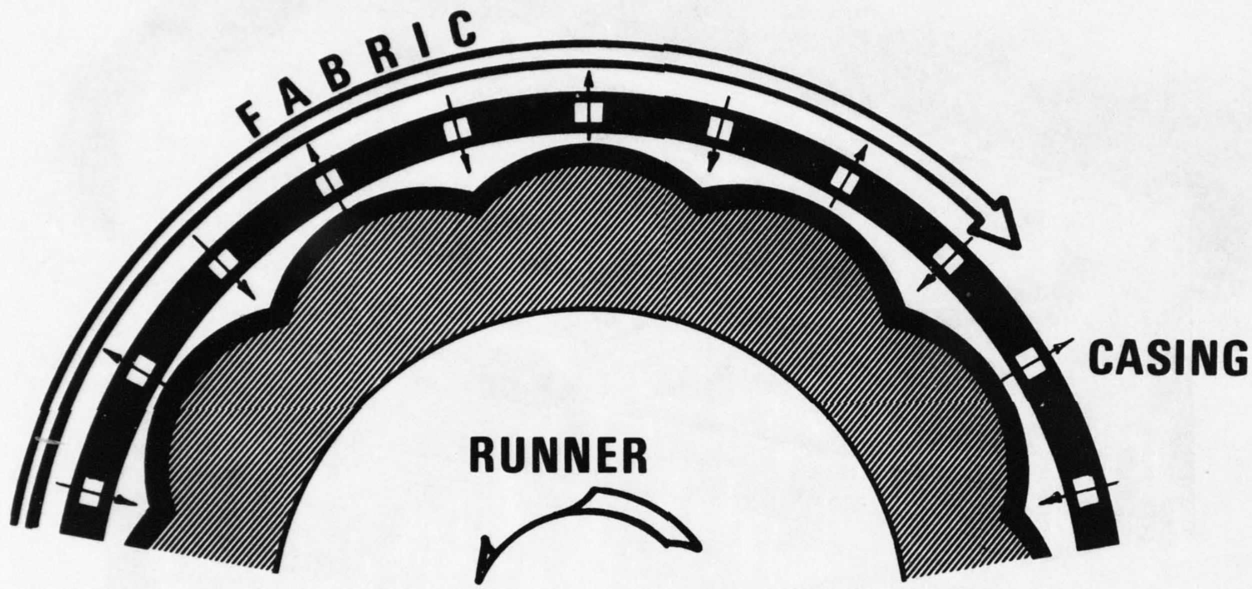

Figure 2. Low frequency vibration device.

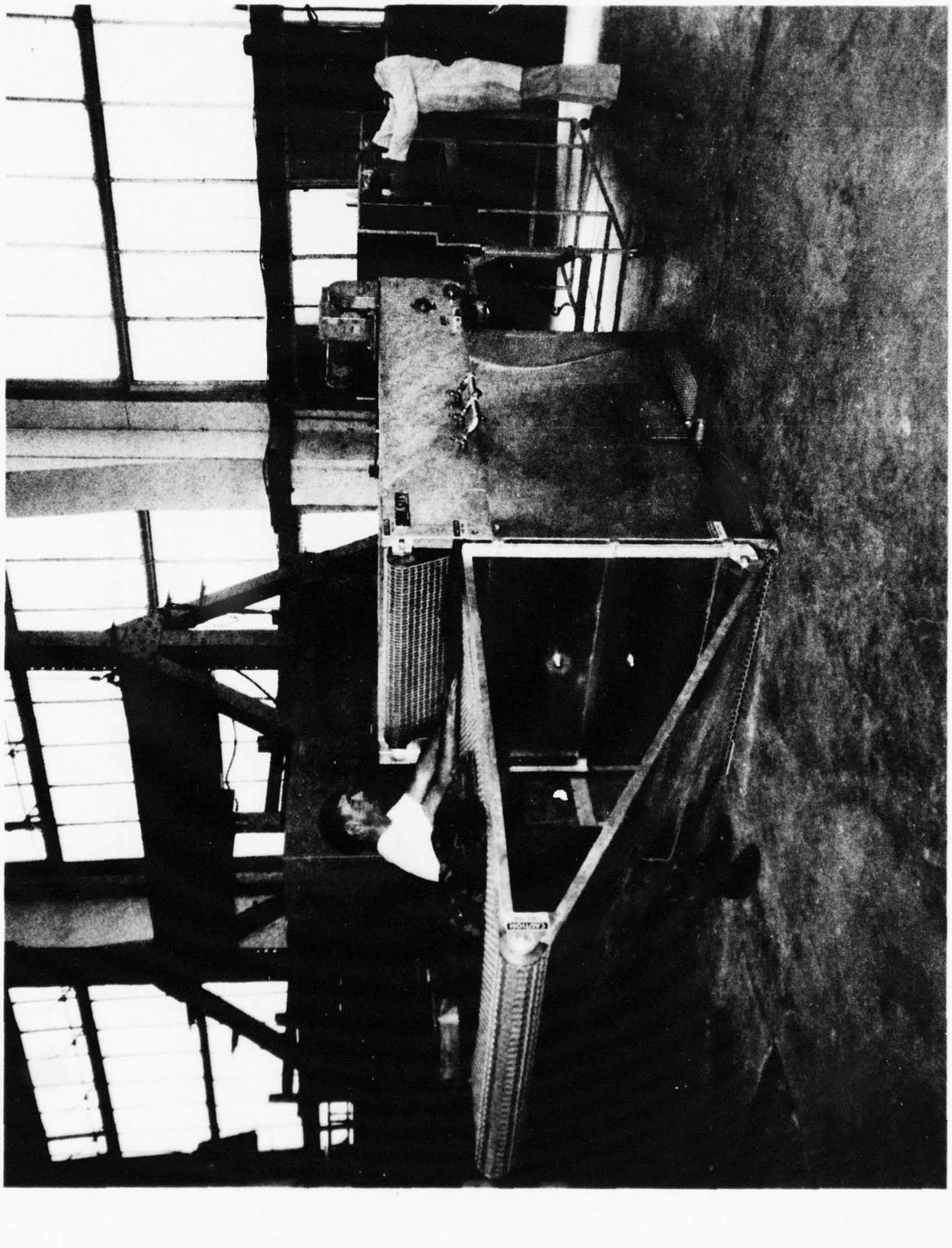

Figure 3. Washing and drying experimental model.

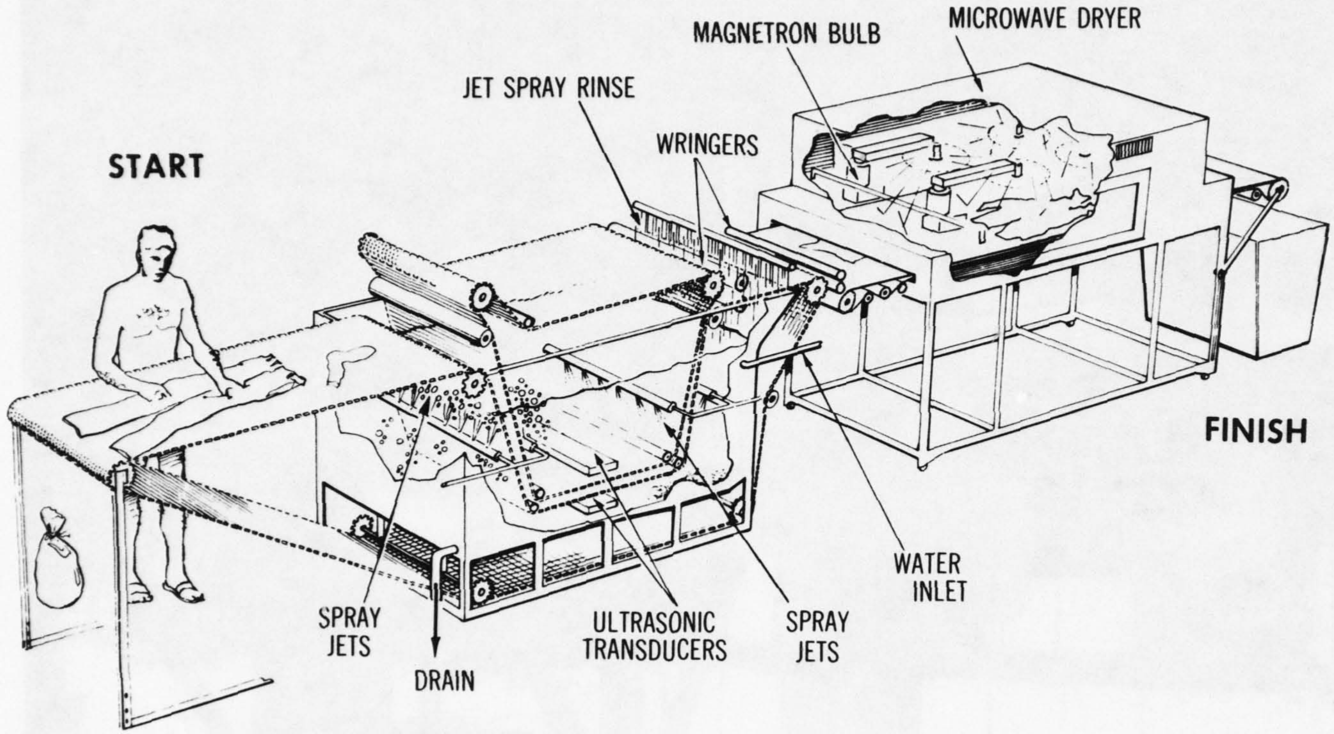

Figure 4. MARCORPS experimental laundry system.

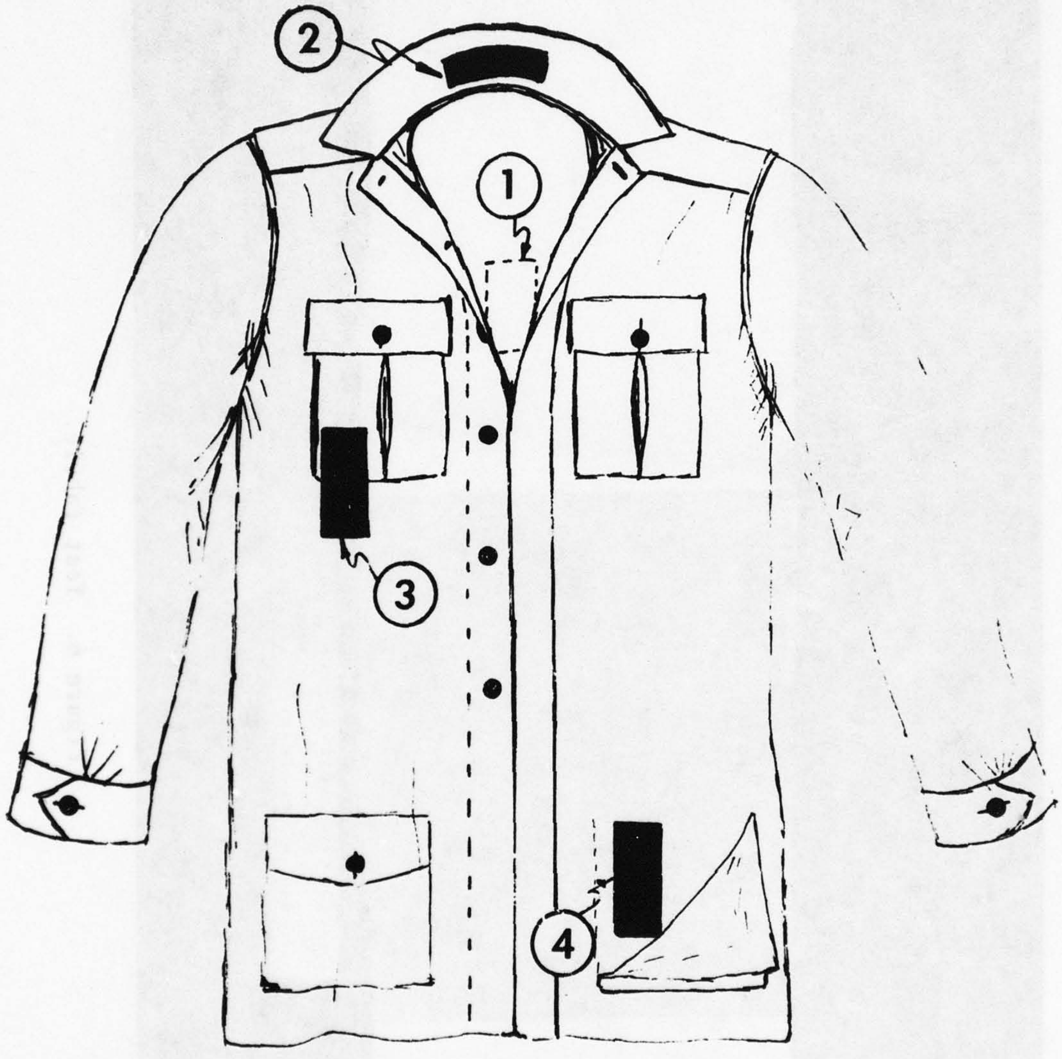

Figure 5. Test fabric cleaning positions.

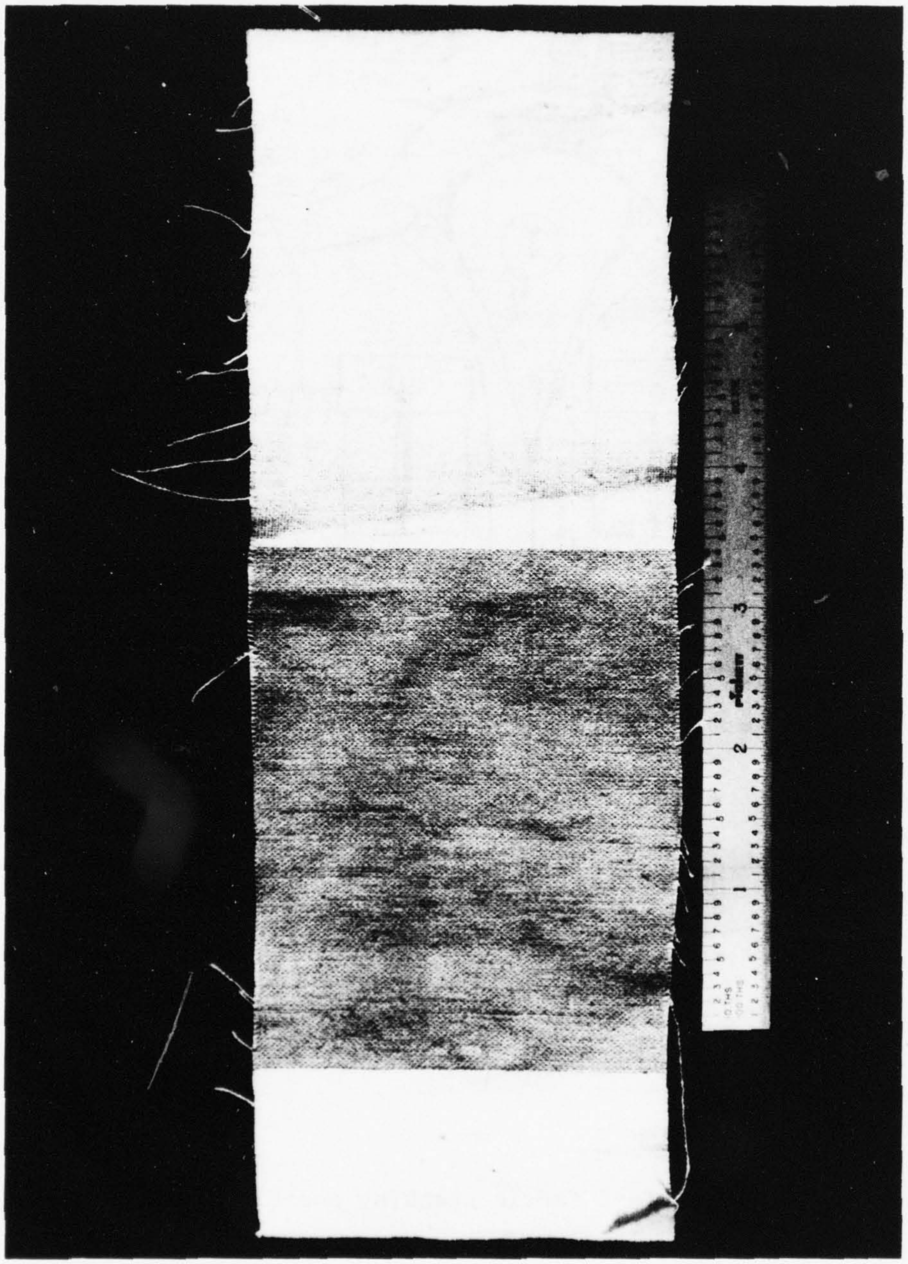

Figure 6. Test fabric.

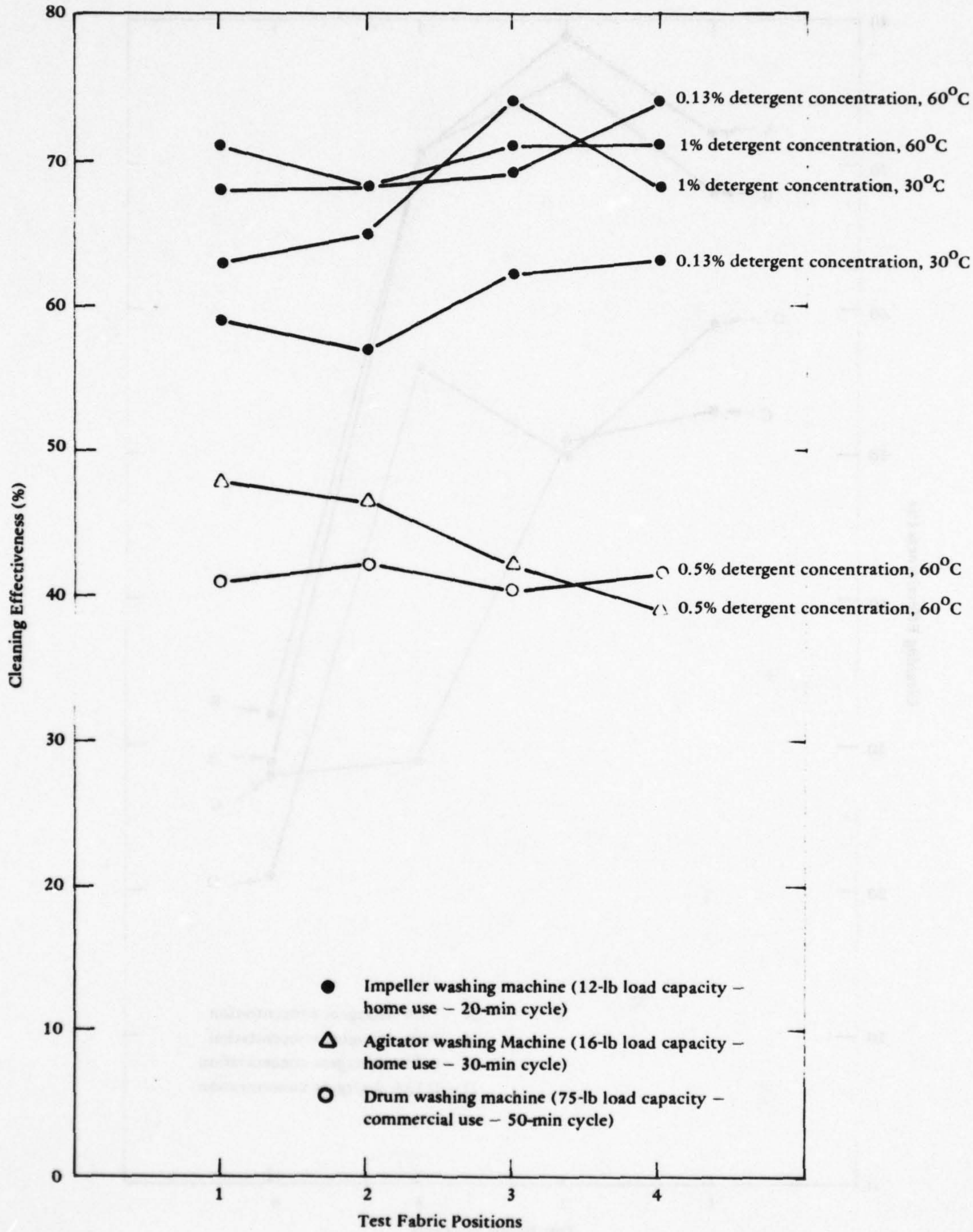

Figure 7. Cleaning effectiveness with conventional washing machines.

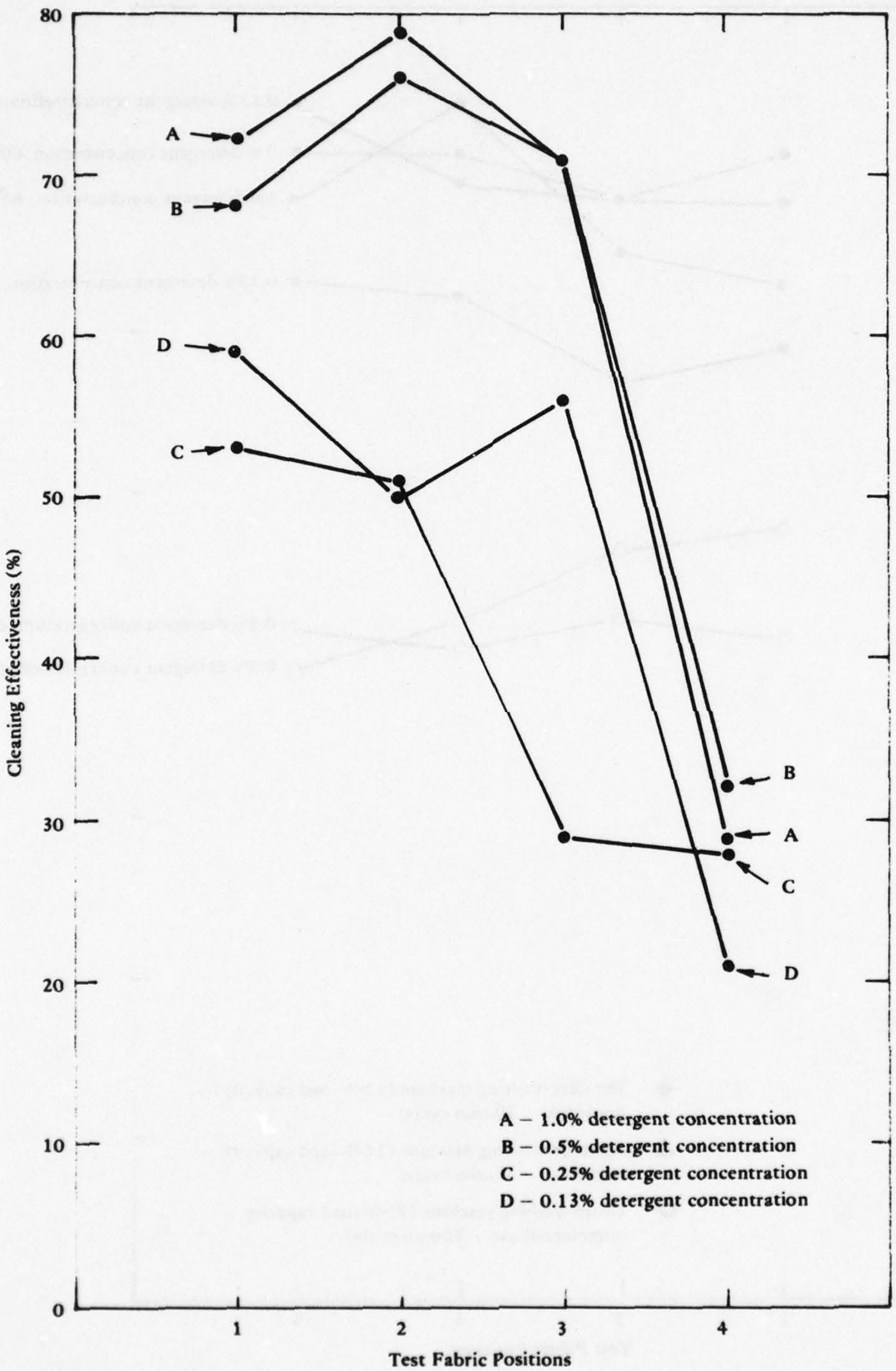

Figure 8. Cleaning effectiveness with 20°C water temperature, low frequency vibration, high velocity water jets for a 5-minute cycle.

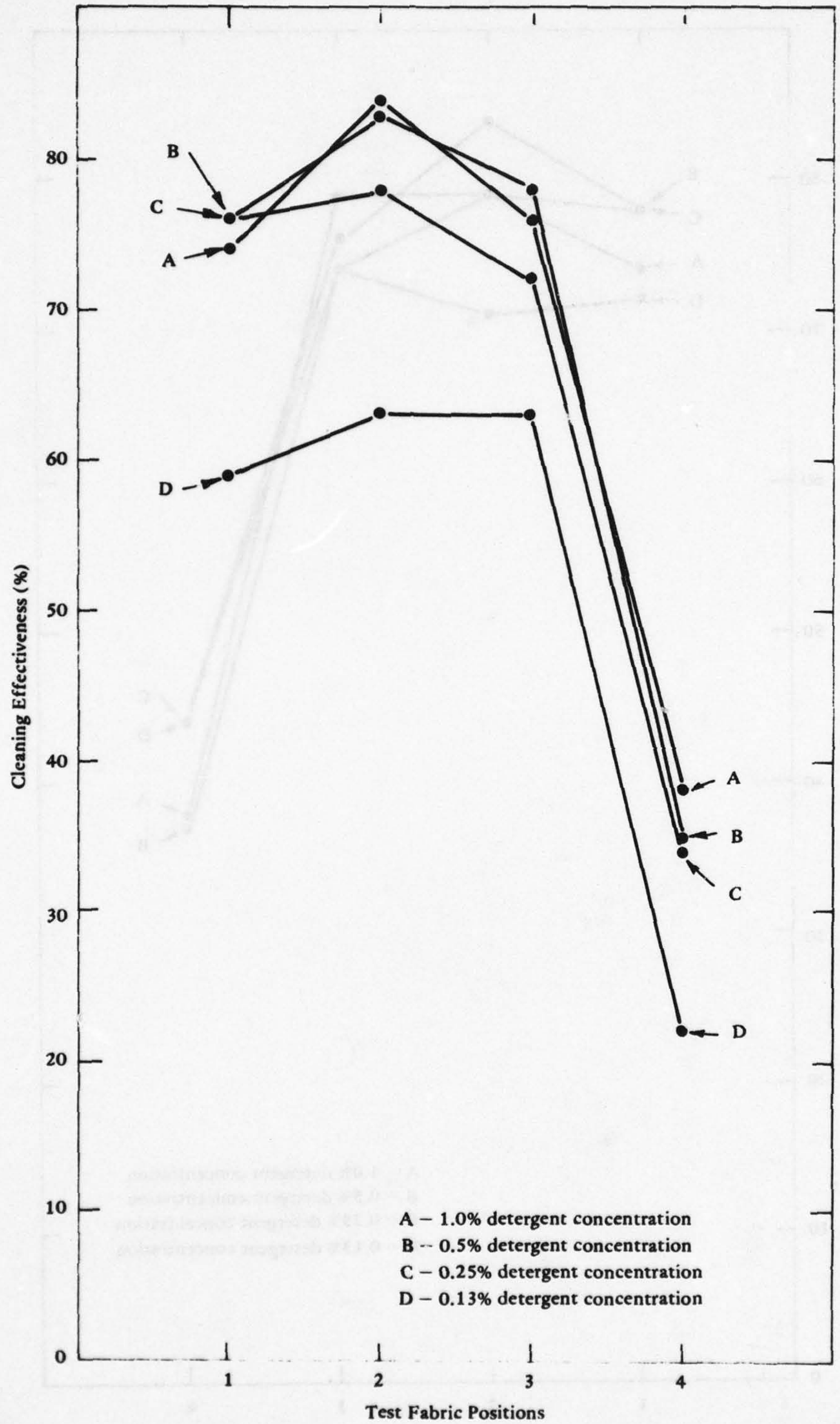

Figure 9. Cleaning effectiveness with 30°C water temperature, low frequency vibration, high velocity water jets for a 5-minute cycle.

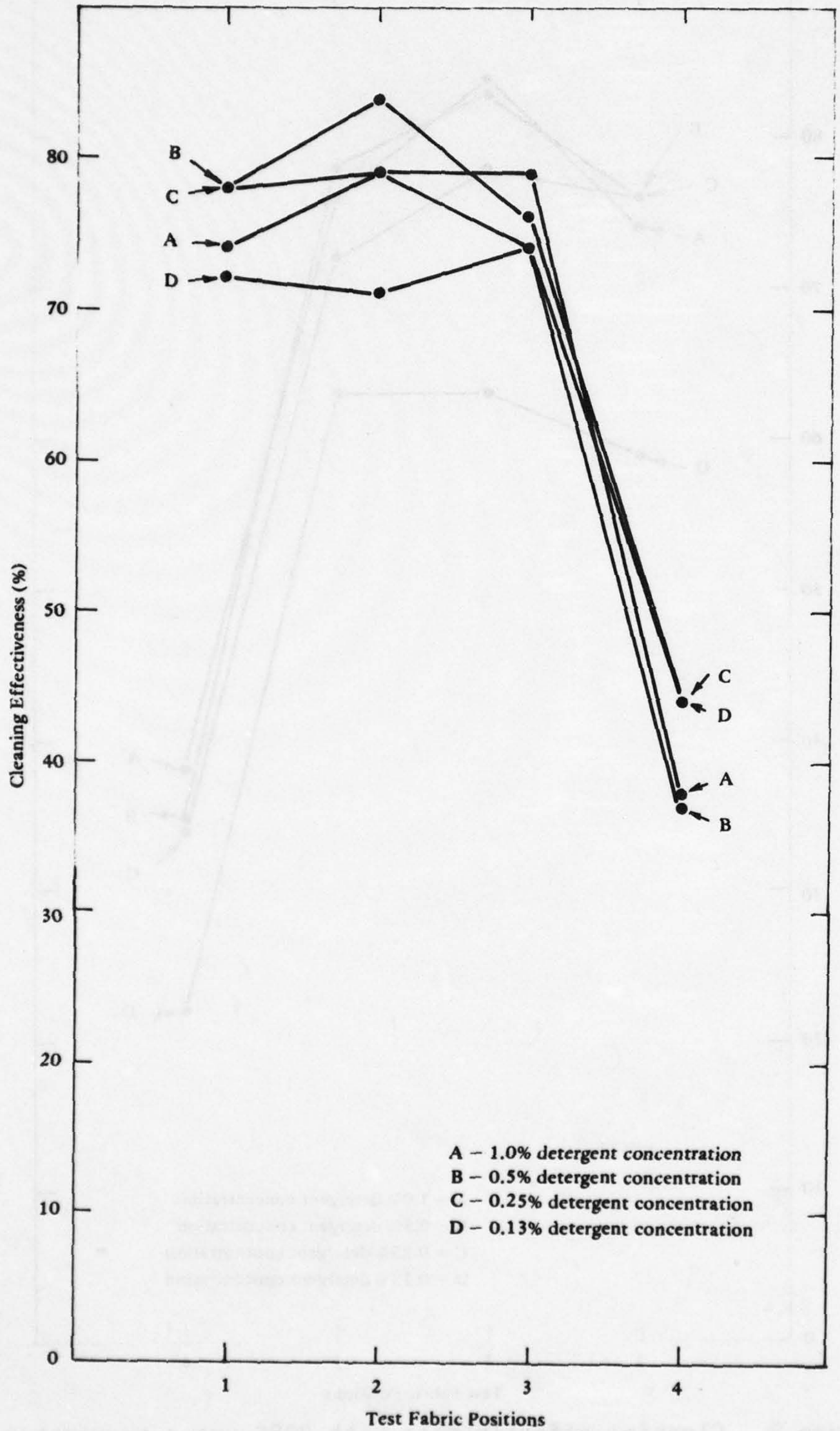

Figure 10. Cleaning effectiveness with 50°C water temperature, low frequency vibration, high velocity water jets for a 5-minute cycle.

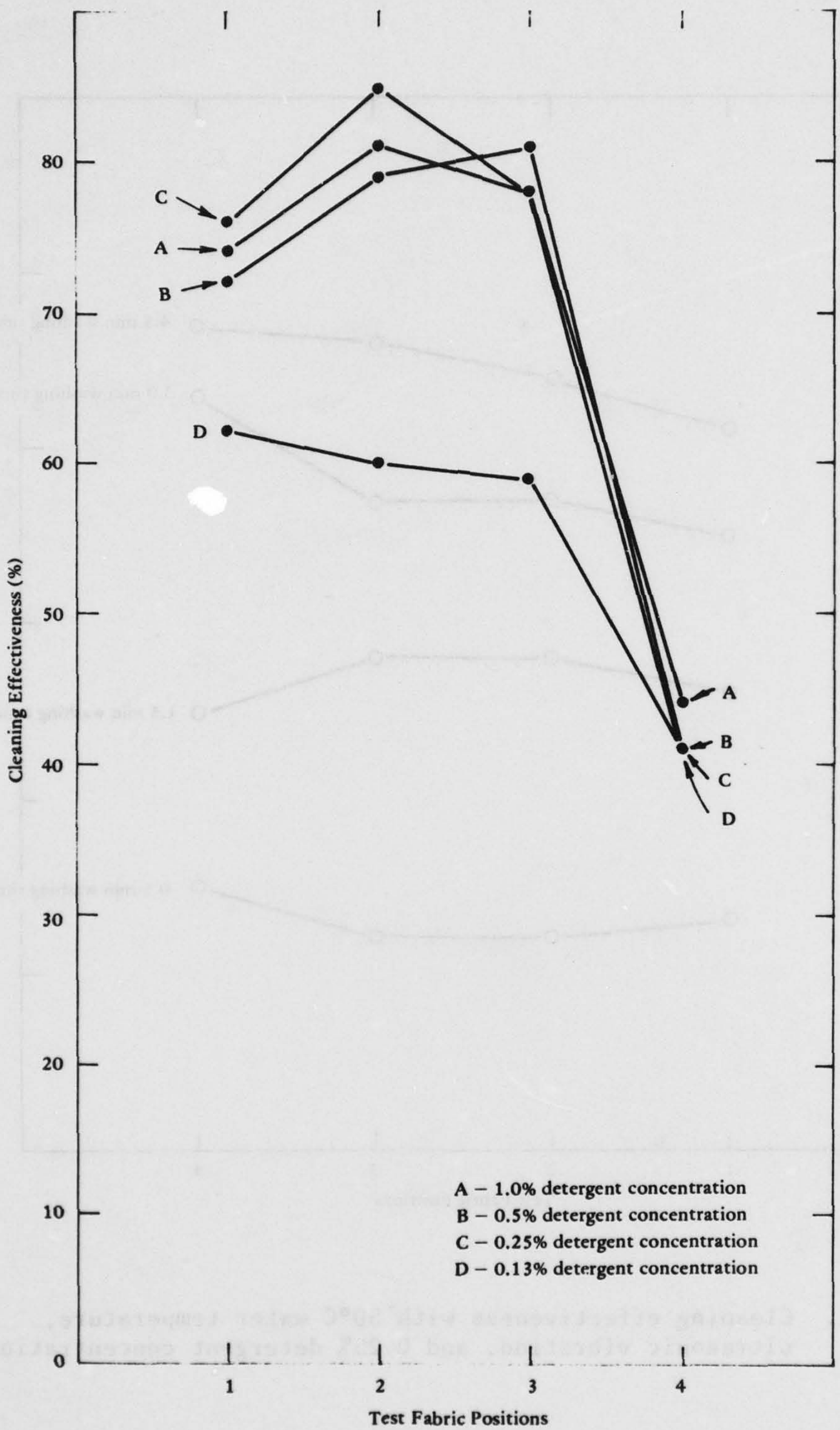

Figure 11. Cleaning effectiveness with 60°C water temperature, low frequency vibration, high velocity water jets for a 5-minute cycle.

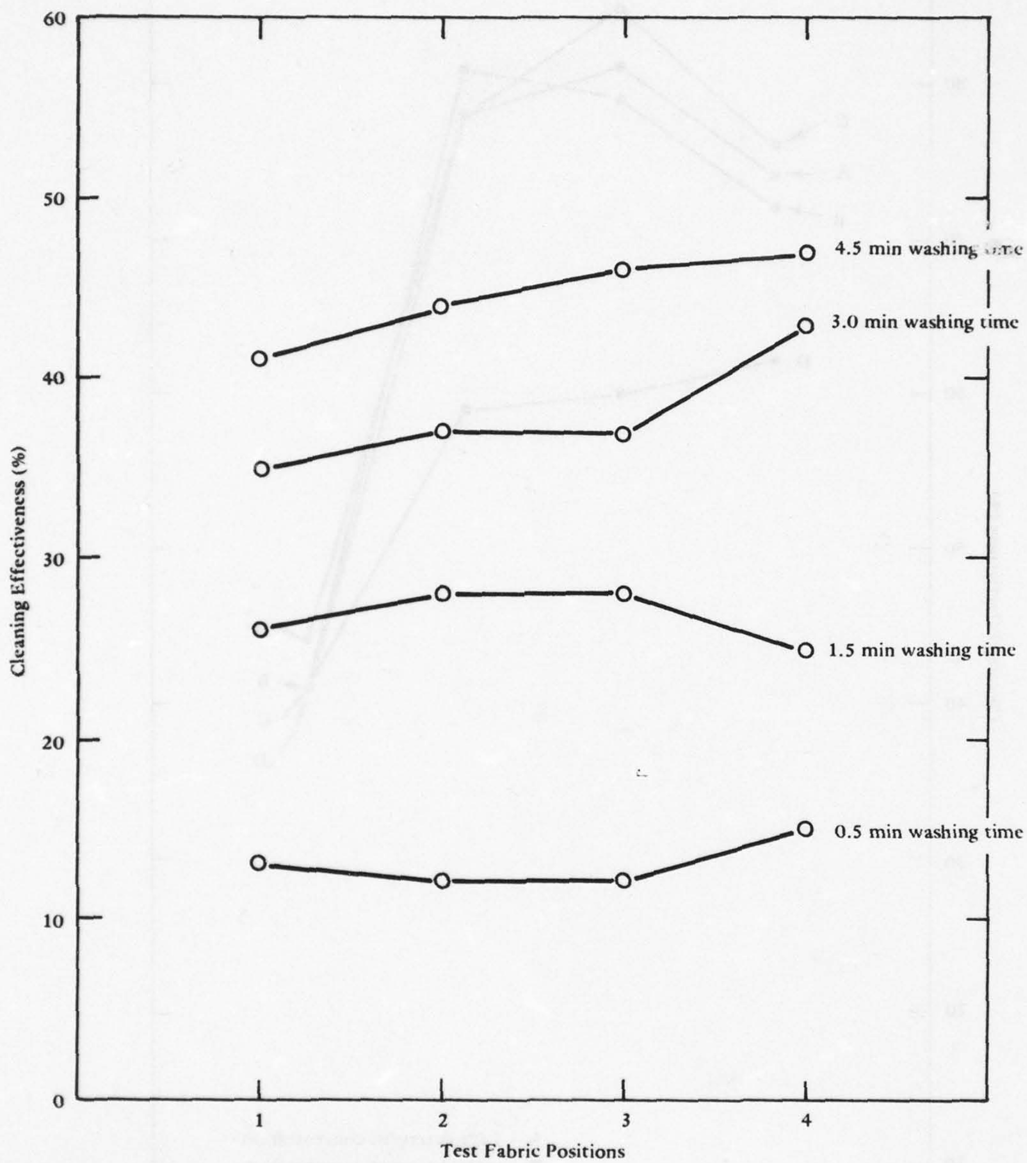

Figure 12. Cleaning effectiveness with 50°C water temperature, ultrasonic vibration, and 0.25% detergent concentration.

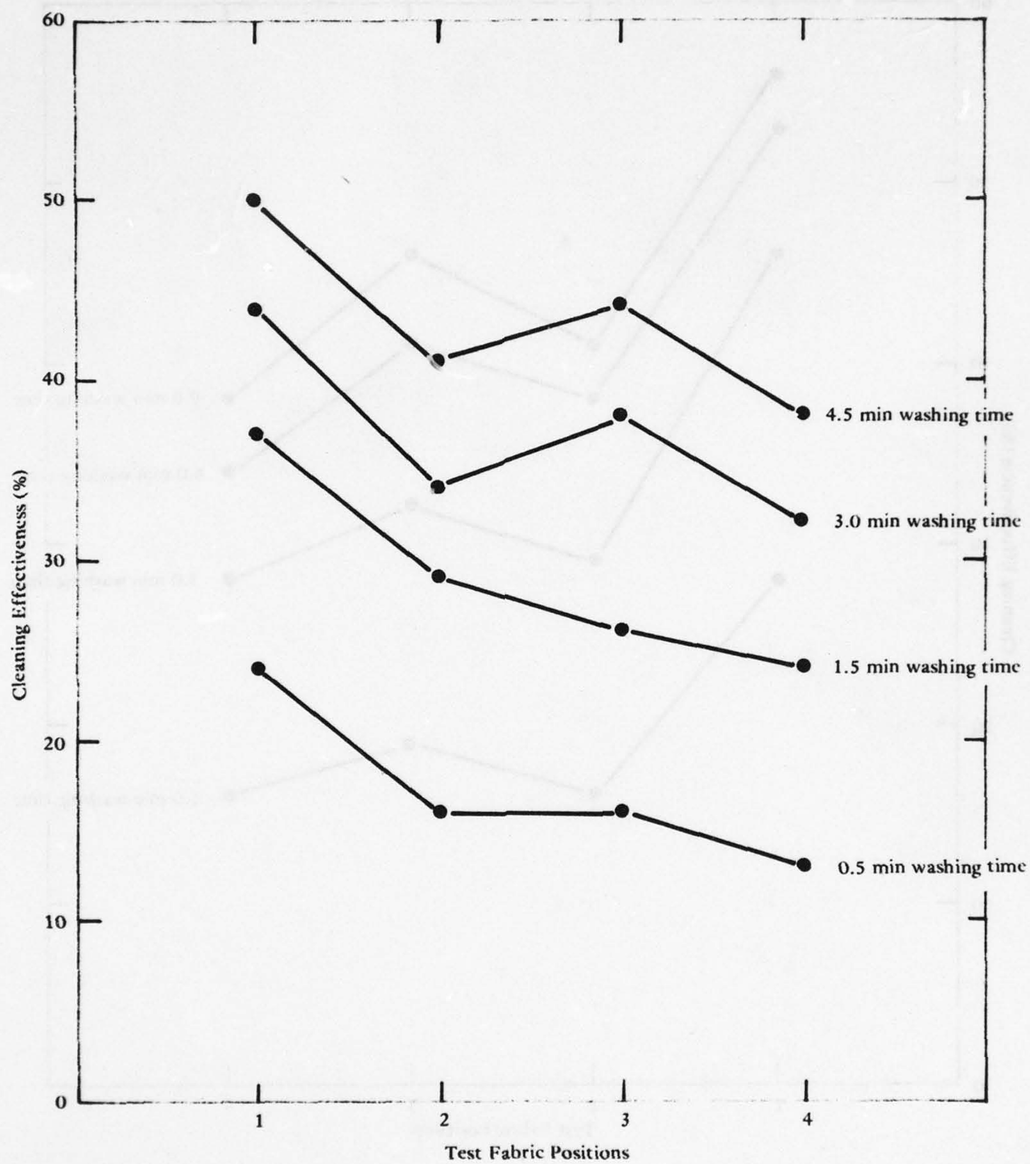

Figure 13. Cleaning effectiveness with 50°C water temperature, low velocity water jets, and 0.25% detergent concentration.

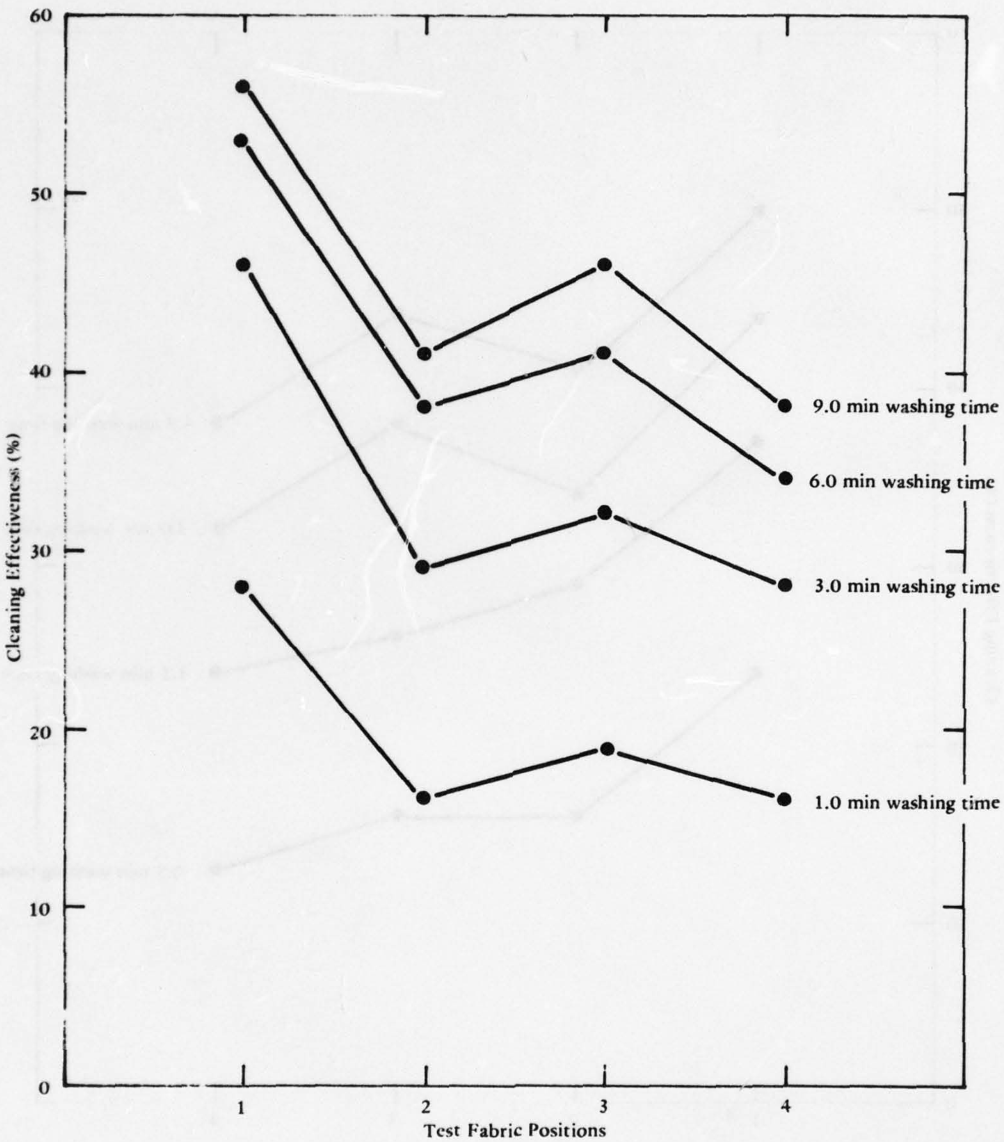

Figure 14. Cleaning effectiveness with 50°C water temperature, ultrasonic vibration, low velocity water jets, and 0.25% detergent concentration.

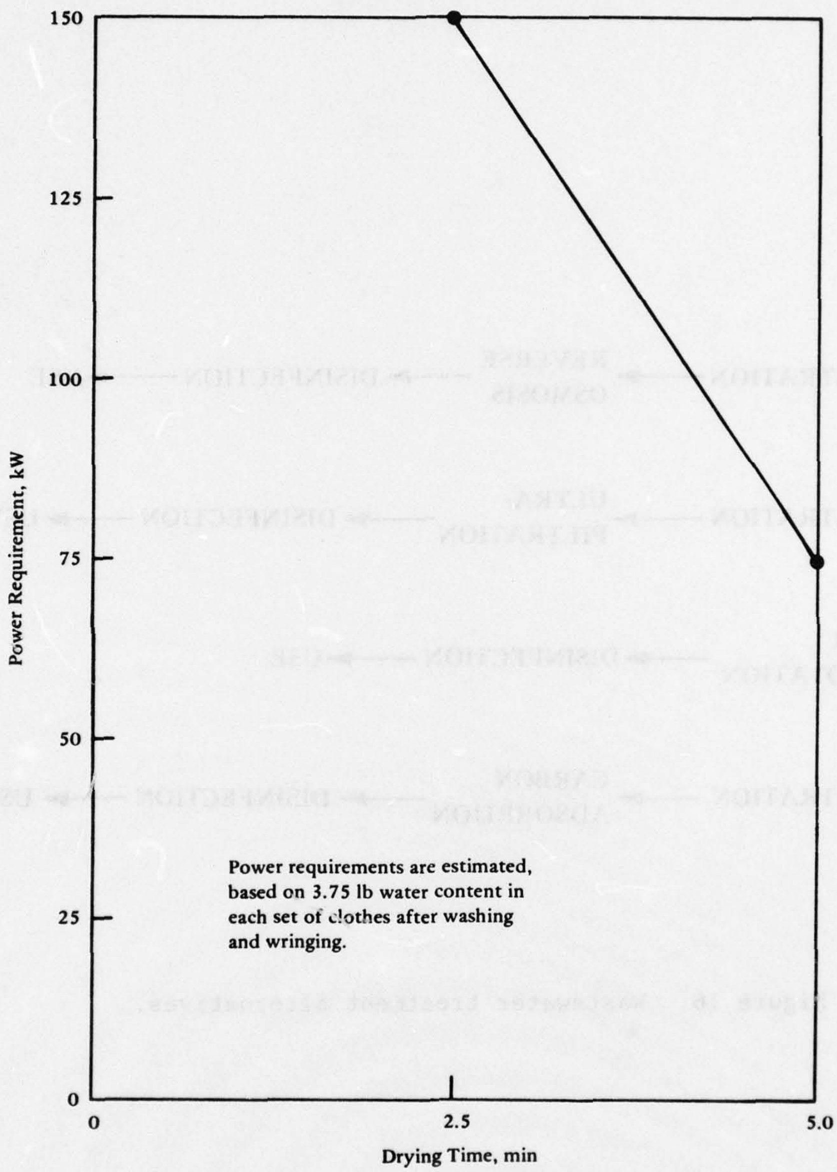

Figure 15. Microwave dryer power requirement.

1 FILTRATION → REVERSE OSMOSIS → DISINFECTION → USE

2 FILTRATION → ULTRA-FILTRATION → DISINFECTION → USE

3 AIR FLOTATION → DISINFECTION → USE

4 FILTRATION → CARBON ADSORPTION → DISINFECTION → USE

Figure 16. Wastewater treatment alternatives.

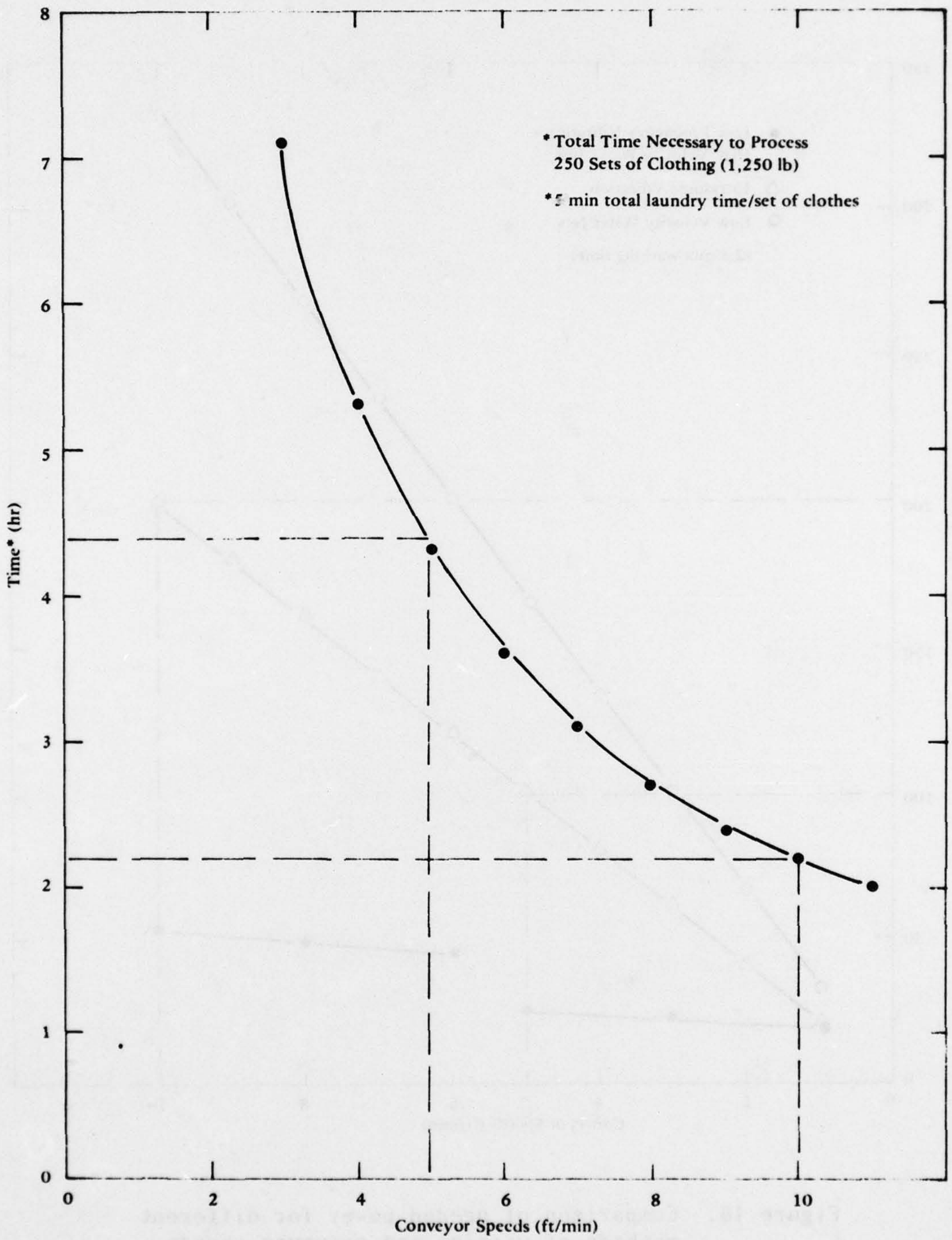

Figure 17. Total time necessary to process 250 sets of clothing (1,250 pounds) at various conveyor speeds.

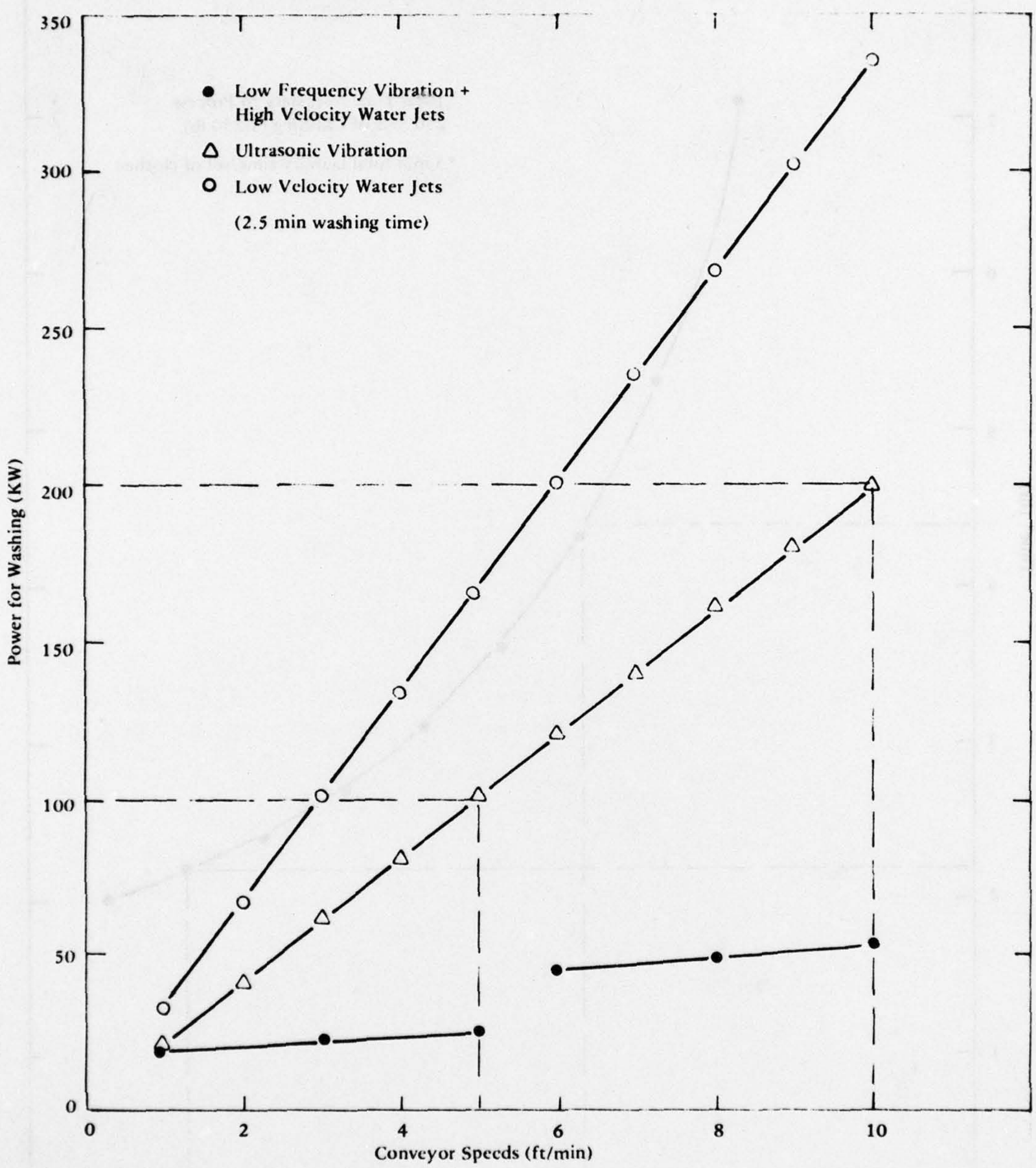

Figure 18. Comparison of needed power for different methods of washing and conveyor speeds.

Table 1. Test Conditions for Different Washing Methods

Washing Method	Cycle Time (min)	Water Temperature (°C)	Detergent Concentration (%)
Ultrasonic Vibration	5 60	50	0.25
Low Velocity Water Jets	5 60	50	0.25
Ultrasonic Vibration and Low Velocity Water Jets	5 60	50	0.25
Low Frequency Vibration and High Velocity Water Jets	5	20, 30 50, 60[a]	0.125, 0.25 0.5, 1.0[a]
Drum Washing Machine	40[b]	70	0.5
Agitator Washing Machine	30[b]	60	0.5
Impeller Washing Machine	20[b]	30, 60[a]	0.125, 1.0[a]

[a]Each detergent concentration was tested at each temperature.

[b]Normal.

Table 2. Water Absorption Test Data

Type of Clothing	Clothing Weight (lb)			Water to be Evaporated (lb)
	Dry	Dripping Wet	After Wringing	
Green Utility				
Jacket	1.17	2.87	2.52	1.35
Trousers	1.25	3.12	2.45	1.20
Camouflage				
Jacket	1.24	3.23	2.38	1.14
Trousers	1.36	3.23	2.54	1.18

Table 3. Microwave Dryer Test Data

Run No.[a]	Power Input			Clothes Weight (lb)			Drying Time (min)[b]		Overall Efficiency (%)
	Volts	Amps	kW	Dry	Wet	Difference	Theoretical	Actual	
1	210	40	8.4	1.23	3.97	2.74[c]	6.5	24	27
2	210	49	10.29	1.23	3.97	2.74[c]	5.3	19.7	27
3[d]	210	59	12.39	1.23	3.97	2.74[c]	4.4	15.5	28
4	210	68	14.28	1.22	3.97	2.75[c]	3.8	13.0	29
5	210	55	11.55	1.28	2.73	1.45	2.5	10.0	25
6	208	63	13.10	1.23	2.54	1.31	2.0	8.0	25
7[d]	205	70	14.35	1.19	2.62	1.43	2.0	8.0	25
8	208	55	11.44	1.46	3.05	1.59	2.8	11.2	25
9	206	63	12.98	1.45	3.03	1.58	2.4	9.0	27
10	203	70	14.21	1.48	3.04	1.56	2.2	8.7	25
11	205	78	15.99	1.45	3.10	1.64	2.1	8.8	24
12	209	53	11.08	1.34	2.62	1.28	2.3	9.5	25
13	208	63	13.10	1.35	2.61	1.26	1.9	7.0	27
14	206	70	14.42	1.35	2.63	1.28	1.8	6.8	26
15	205	78	15.99	1.28	2.64	1.36	1.7	6.0	28
Average									26.2

[a]Runs 1 through 11 used 100% cotton green utility jacket or trousers. Runs 12 through 15 used 100% cotton camouflage jacket.

[b]Theoretical drying time is calculated by using 1,125 Btu (or 0.33 kWh) heat energy required for evaporating 1 pound of water.

[c]Poor wringing resulted in a moisture-content-to-dry-weight ratio of about 2 to 1. With good wringing, the ratio should be 1 to 2.

[b]Jacket tested was slightly burned due to over drying; i.e., jacket's dried weight was less than its original weight.

Table 4. Water Quality Standards for Shower/Laundry

Parameters	NASA[a]
Physical	
Conductance, μmh-cm^{-1} @ 25°C	2,000
Color, cobalt units	15
Odor	Nonobjectionable
Foaming	Nonpersistent more than 15 seconds
Chemical	
Sodium chloride, mg/l	1,000
Urea, mg/l	50
Latic acid, mg/l	50
Ammonia nitrogen, mg/l	5.0
Total organic carbon, mg/l	200
Total dissolved solids, mg/l	1,500
pH	5.0-7.5
LAS[b]	0.5
Microbiological	
Coliform, no./100 ml	1,000

[a]These were established for long space travel.

[b]LAS concentration was taken from the Proposed Laundry Water Reuse Standards from U.S. Coast Guard.

Table 5. Laundry/Shower Wastewater Treatment Tests

Constituent	Tap Water	Laundry/ Shower Wastewater	Test No. 1, Filtration Effluent	Test No. 2, Filtration and Air Flotation Effluent	Test No. 3, Ultra-filtration Effluent	Test No. 4, Coagulation/ Flocculation and Ultra-filtration Effluent
COD (mg/l)	7.7	1,610	891	358	303	269
pH	7.75	9.45	9.32	9.48	9.12	5.35
Total Dissolved Solids (mg/l)	1,000	2,116	1,640	2,052	1,616	1,720
Specific Conductance (μmho/cm)	1,160	2,100	1,880	2,000	1,700	2,600
Apparent Color	<5	10	10	10	15	<5
Total Alkalinity (mg/l)	194.2	414.4	317.5	348.6	5.4	6.0
Total Kjeldahl Nitrogen (mg/l)	4	18	18	15	13	1.7
Suspended Solids (mg/l)	0.35	1,180	249	369	18.5	9.3
Turbidity (Jackson Units)	<25	380	450	750	148	<25

Table 6. Laundry/Shower Power Requirements for 5-Minute Laundry Cycle

[1,250 lb clothing for 250 men processed within allotted time]

Total Time Used	Washer	Dryer	Hot Water (Shower)	Water Recycle	Pumping	Power Generator Size (kW)
4.5 hours[a]	34	75	36	15	10	170
2.5 hours[b]	36	149	36	15	10	246

[a]Processing time corresponds to a 10-fpm conveyor speed and 2-min shower time.

[b]Processing time corresponds to a 5-fpm conveyor speed and 4-min shower time.

Appendix

EVALUATION CRITERIA FOR LAUNDRY/SHOWER MODULE

1. HEALTH HAZARD

The laundry/shower module must accept, process, and deliver clothing, and shower personnel without adversely affecting personnel's health.

1.1. PATHOGENIC MICROORGANISMS - Laundered clothes must be free from pathogenic microorganisms as a result of the laundry process. Disinfection of the wash and rinse waters is necessary; likewise, shower water must undergo disinfection before each use.

1.2. NOISE - Noise emanating from the laundry section must not exceed 85 dba at a distance of 3 feet from the laundry section enclosure. This noise limit also exists within the module's dressing and undressing rooms and within the shower section.

2. ENERGY REQUIREMENTS

Excessive power requirements must be avoided to allow field use of the laundry/shower module. A single, standard power source, without a multifuel logistic burden, is required.

2.1. POWER CONSUMPTION - The overall power requirement for the laundry and shower sections must not exceed the power available from a 200-kW power generator (10,500-lb weight).

2.2. POWER SOURCE - Electricity is the acceptable power source for all operations.

3. USER ACCEPTABILITY

The laundry and showering processes must be fully acceptable to user personnel in order for the laundry/shower module to be used effectively.

3.1. CLOTHES CLEANING - Removal of dirt and stains from clothes should be identical to the dirt and stains removed by an industrial-sized washing machine (>50-lb load).

3.2. CLOTHES DRYING - Removal of moisture from clothes should be identical to the moisture removed by an industrial-sized drying machine (>50-lb load) to make the fabric dry to the touch.

3.3. LAUNDERING TIME - The time necessary to wash and dry clothes must be compatible with the showering process; therefore, the laundering process should be performed within 5 minutes.

3.4. CONTINUOUS USAGE - The laundering process must be capable of continuous usage by personnel without interruption. Loading/unloading of machines within the laundering process is unacceptable.

3.5. OPERATIONAL SIMPLICITY - Operation should be "turn key" and without complicated procedures that user personnel find difficult to use.

3.6. ENCLOSURE SIZE - Dressing and undressing rooms must be adequate in size to facilitate use by a minimum of four people at one time. Therefore, minimum floor area for each room is 16 sq ft (4 sq ft/person).

4. INSTALLATION/RELOCATABILITY

Minimum time and manpower can be expended for deployment (installation) and re-packing while in a field environment.

4.1. SITE PREPARATION - Site preparation should consist only of providing a relatively level surface for all containers.

4.2. EXTERNAL ATTACHMENTS - The only external attachments connected to the laundry/shower module are power and water (both fresh and exhaust) lines. The laundry/shower module must be self-contained for all other equipment necessary.

4.3. INSTALLATION/REPACKING TIME - The time required for installation or repacking should not exceed 30 minutes each.

4.4. MANPOWER - Manpower required for installation and repacking must not exceed two men, only one of which need be trained in the module's operation.

4.5. TRAINING - Training necessary for installation and repacking and operation will be included in a 2-day training course. Self-explanatory, self-evident instructions will also be provided on all equipment.

4.6. EQUIPMENT - Equipment necessary for installation, repacking and operation must be housed within the module.

5. WATER REQUIREMENT

The laundry/shower module's water requirements must not be a logistic burden in the field environment.

5.1. WATER VOLUME - The volume of water necessary to launder and bathe 250 people daily must not exceed the lift capability of a moderately powered helicopter. Therefore, 1,000 gallons (8,340 pounds) is the maximum water volume allowed per 250 users. Since the water usage per person is actually 10 gallons (5 gal/person/shower; 5 gal/person/5 lb of clothing), the volume of water required is 2,500 gallons. Therefore, reusing the water a number of times will be necessary.

5.2. WATER TEMPERATURE - The laundry process must not require a water temperature greater than 120°F.

5.3. WATER QUALITY - The quality of water must not degrade below quality standards outlined in the wash-water reuse standards adopted by the National Aeronautics and Space Administration for prolonged space flight. In addition, complete disinfection must be provided for all shower and laundry water. When more comprehensive body contact water standards are made available, the new standards will be adhered to.

6. CHEMICAL REQUIREMENT

The chemical quantities used per day must not be a logistic burden in the field environment.

6.1. LAUNDRY DETERGENT - Laundry detergent used daily must be transported with the laundry and should not exceed 100 lb/1,250 lb of clothing (12.5 lb clothing/lb detergent).

6.2. RECYCLING CHEMICALS - Chemicals used daily for water recycling purposes must be transported with the laundry/shower module and should not exceed 15 pounds of chemicals per day (laundry and shower for 250 men).

7. TRANSPORTATION

The laundry/shower module must be compatible with standard containerization systems to facilitate use by all transportation resources of opportunity.

7.1. MODULAR - Each laundry/shower unit must be modular in concept - one complete unit per module (excluding power and water sources).

7.2. SIZE - A module to contain one laundry and one shower section is 8 ft wide x 8 ft high x 20 ft long.

7.3. WEIGHT - The weight of the laundry/shower module must not exceed the lift capability of a moderately powered helicopter (10,000 lb).

8. OPERATION RELIABILITY

All process equipment must be capable of sustaining adverse handling, transportation, and operating conditions.

8.1. DURABILITY - The module and equipment must be capable of withstanding a 6-inch drop.

8.2. AUTOMATIC OPERATION - Instrumentation must complement all unit processes to enable monitoring of all operations. Automatic operation must alleviate continuous manual adjustment of equipment.

8.3. SIMPLE (FAILSAFE) MECHANISMS - Simplicity must be inherent throughout the laundry/shower module design. Complicated systems do not complement the military field environment.

9. MAINTAINABILITY

Maintenance and logistic support must be compatible with a remote field environment.

9.1. OPERATOR - One operator will be available to operate both the laundry and shower sections of the module. Training will be provided in a 2-day training course.

9.2. MAJOR MAINTENANCE - Major maintenance must not be required within a 6-month period.

9.3. MINOR MAINTENANCE - Minor maintenance will be taught within the 2-day training course and will not exceed 1 hour daily.

9.4. TOOLS - All tools necessary for minor maintenance must be contained within the laundry/shower module.

10. SAFETY

Personnel must not be exposed to danger as a result of any of the laundry/shower operations or equipment.

10.1. EQUIPMENT MALFUNCTION - All potential equipment malfunctions must not be capable of damaging other equipment or inflicting injury to user personnel.

10.2. EXPOSED EQUIPMENT - All exposed equipment in contact with user personnel must not be capable of causing electrical shock or burns. Maximum temperature of exposed parts is 130°F. Conveyor use must not be capable of causing injury due to its movement.

10.3. EXPLOSION HAZARD - No explosive liquids should be used internal to the laundry process (e.g., solvents). Equipment capable of explosion must contain failsafe mechanisms to offset potential danger.

10.4. RADIATION HAZARD - Heat or other radiating waves emanating from the laundry section must not pose a danger to user personnel. Existing government standards for microwave leakage will be adhered to.

11. SHELF LIFE

All equipment used within the laundry/shower module must be capable of remaining inactive for lengthy periods of time before, and in between, usage.

11.1. STORAGE LIFE - A minimum 5-year storage life before use is required. In addition to shelf life before use, a 5-year service life encompassing a minimum of three 6-month deployments is also required.

11.2. STORAGE ENVIRONMENT - All components must be capable of storage without unique environmental conditions. Special conditions such as humidity, temperature, and light are unacceptable.